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Northern Hemisphere Atlas of 1-Minute Rainfall Rates

PAUL TATTELMAN
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4 October 1983

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METEOROLOGY DIVISION PROJECT 6670
AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MASSACHUSETTS 01731

AIR FORCE SYSTEMS COMMAND, USAF

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FOR THE COMMANDER

Donald D. Grantham

DONALD D. GRANTHAM
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Director, Meteorology Division

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Errata

Page 10, seventh line from top:

Change: 483 Southern Hemisphere locations

to read: 3631 Northern Hemisphere locations

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A model for estimating 1-min rainfall rates at a location for which routine climatic data are available was used to produce this atlas. Even though data were available for 3631 locations, considerable subjectivity and smoothing of the analyses were required because of the low station-density outside of North America and Europe. Northern Hemisphere analyses of rainfall rates equalled or exceeded 0.01, 0.05, 0.10, 0.50, and 1.0 percent of the time are presented for four mid-season months. Analyses of the

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highest rainfall rates for the same frequencies of occurrence regardless of the month in which they occur and companion analyses of the month in which the highest rate occurs are also presented.

Preface

We are grateful for the early programming support provided by Jack Mettauer, Regis College. Although very ill, he worked tirelessly until his sudden death during the course of this effort. We would like to thank Daniel Dechichio, Jr., Bedford Research Associates, for his responsive and timely programming support. We also thank Don Aiken, AFGL, for his programming support; Lisa Phillips, Systems and Applied Sciences Corp., for her extensive contribution to analyzing the charts; Arthur Kantor, AFGL, for his support and advice; and Helen Connell, AFGL, for typing the report.

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1. INTRODUCTION

Knowledge of the frequency distribution of 1-min precipitation rates is important to the design and operation of many types of equipment. Precipitation, especially at heavier intensities, attenuates microwave signals of Air Force systems used in satellite detection and tracking, communications, air traffic control, and weaponry. Erosion caused by rain is important to the design and operation of helicopter rotor blades, leading edges of aircraft and missiles, and fuses on airborne ordnance. Intense rainfall can cause jet engines to malfunction and can penetrate protective coverings on exposed electronic and mechanical materiel.

Rainfall climatologies are available for thousands of locations worldwide, in many instances for more than 100 years. However, data collection was oriented toward agricultural and hydrological purposes for which monthly, daily, and, less commonly, 3- and 6-hourly totals were collected. Precipitation data for intervals of 3 h down to 5 min are available for many locations in the United States, but for few locations in other parts of the world. Much of the meager amount of data on 1-min rates were collected during special field programs conducted for limited time periods (1-3 years). This has prompted the development of numerous models to estimate 1-min rates (often referred to as instantaneous rates). Tattelman and

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Grantham[1] discuss sources of 1-min data and compare models for estimating 1-min rates.

A model for estimating rates on a monthly basis was developed at AFGL by Lenhard.[2] Because of the importance of worst-month considerations for design and operation problems, an improved monthly model that overcomes some of the shortcomings of the Lenhard model was developed by Tattelman and Scharr.[3] This model was used to estimate 1-min rainfall rates at 483 Southern Hemisphere locations to produce this atlas.

2. THE MODEL

The Tattelman-Scharr model for estimating 1-min rainfall rates was developed using stepwise multiple regression analysis. Data for the analysis were taken from reports by Jones and Sims[4] and Sims and Jones.[5] These reports include the monthly frequency distribution of 1-min rates for the 12 locations in Table 1. Three years of data were available for Urbana and two years for Paris, but much less was available for the other stations. Therefore, data for the same month in different years were averaged to avoid bias by the stations with longer records. This resulted in 122 monthly instantaneous precipitation-rate distributions for the 12 locations.

The model is made up of six regression equations to estimate rates that are equalled or exceeded for exceedance levels (p) = 0.01, 0.05, 0.10, 0.50, 1.0, and 2.0 percent of the time during a month. Information required to make the estimates for each of the six exceedance levels (p) consists of monthly mean temperature, monthly mean precipitation, number of days in the month with precipitation (based on any of three threshold values that define a rainy day), and latitude. The mini-

1. Tattelman, P., and Grantham, D.D. (1982) A survey of techniques for estimating short-duration precipitation rate statistics, Air Force Surveys in Geophysics No. 441, AFGL-TR-82-0357, AD A125705.

2. Lenhard, R.W. (1974) Precipitation intensity and extent, J. Rech. Atmos. 8:375-384.

3. Tattelman, P., and Scharr, K.G. (1983) A model for estimating 1-minute rainfall rates, J. Clim. Appl. Meteorol. 22 (No. 9).

4. Jones, D.M.A., and Sims, A.L. (1971) Climatology of instantaneous precipitation rates, AFCRL-TR-72-0430, Final Report, Contract F1962-72-C-0070, AF Cambridge Res. Lab., AD 749878, Illinois State Water Survey, Urbana, Ill.

5. Sims, A.L., and Jones, D.M.A. (1973) Climatology of instantaneous precipitation rates, AFCRL-TR-73-0171, Final Report, Contract F19628-69-C-0052, AF Cambridge Res. Lab., AD 760785, Illinois State Water Survey, Urbana, Ill.

Table 1. Locations and Number of Months of 1-Min Data Available for Model Development. Data for the same month in different years were averaged. The resulting calendar months of data are indicated

Station	Coordinates	Months of Data	Calendar Months of Data
1. Flagstaff, Ariz.	35°14'N, 111°45'W	4	2
2. Franklin, N.C.	35°02'N, 83°28'W	17	12
3. IL Gauge 97 (20 miles NW of Urbana)	40°37'N, 88°15'W	10	10
4. Island Beach, N.J.	39°52'N, 74°05'W	13	12
5. Majuro, Marshall Islands	7°05'N, 171°23'E	13	12
6. Miami, Fla.	25°45'N, 80°19'W	13	12
7. Panama, Canal Zone	09°21'N, 79°59'W	4	4
8. Paris, France	48°52'N, 02°20'E	24	12
9. Preston, England	53°46'N, 02°42'W	12	12
10. Reading, England	51°28'N, 00°59'W	13	12
11. Urbana, Ill.	40°07'N, 88°12'W	36	12
12. Woody Island, Alaska	57°47'N, 150°20'W	11	10

mum threshold amount of precipitation to define a rainy day varies with country. Three of the most common threshold values used worldwide to define a rainy day are 0.25 mm, 1 mm, and 2.54 mm. The number of rainy days during the month based on each of these threshold amounts, as well as monthly precipitation and monthly mean temperature, were observed coincident with the rain-rate frequencies. The number of days per month for another frequently used threshold called a "trace" differed only slightly from the number of days equal to greater than 0.25 mm, and was not used.

The basic form of the model equation is expressed by

$$R_p = A_p + B_p T + C_p I + D_p f(L,T) \tag{1}$$

where R_p is the estimated precipitation rate (mm/min) for exceedance level p, T is the monthly mean temperature (°F or 1.8 x °C + 32), I is a precipitation index (monthly mean precipitation in mm divided by the monthly mean number of days with precipitation), and f(L,T) is a latitude-temperature term. A_p is the constant for exceedance level p, and B_p, C_p, and D_p are multiple regression coefficients for T, I, and f(L,T) respectively for exceedance level p. The term f(L,T) is defined by

$$f(L,T) = \begin{cases} 0 & L \leqslant 23.5° \\ (L - 23.5) \times T & 23.5 < L \leqslant 40° \\ (40 - 23.5) \times T & L > 40° \end{cases} \quad (2)$$

where L is the latitude (degrees and tenths) of the location of interest. This term accounts for the increasing importance of temperature for estimating precipitation rates at latitudes higher than 23.5 N°.

Results of the regression analysis, including the multiple correlation coefficient (R) and the standard error of estimate (SEE), for each of the 6 exceedance levels are given in Tables 2, 3, and 4 for indices based on rainy-day threshold values of 2.54 mm, 1 mm, and 0.25 mm, respectively. The original report on the model should be referred to for a more thorough description of its development and validation.

Table 2. Results of Stepwise Multiple Regression Analysis for Exceedance Levels p = 0.0, 0.05, 0.10, 0.50, 1.0, and 2.0 Percent Based on a Threshold Value of 2.54 mm for I. The regression coefficients are given for each independent variable

p	Constant (A_p)	T (B_p)	$I_{(2.54)}$ (C_p)	f(L,T) (D_p)	R	SEE (mm/min)
.01	-0.91	2.8×10^{-2}	2.3×10^{-2}	-3.4×10^{-4}	0.83	0.43
.05	-0.50	1.6×10^{-2}	1.9×10^{-2}	-3.1×10^{-4}	0.86	0.24
.10	-0.31	1.1×10^{-2}	1.4×10^{-2}	-3.0×10^{-4}	0.85	0.19
.50	-0.01	2.5×10^{-3}	5.4×10^{-3}	-1.5×10^{-4}	0.76	0.09
1.0	0.03	7.4×10^{-4}	2.9×10^{-3}	-7.6×10^{-5}	0.67	0.06
2.0	0.04	-2.0×10^{-4}	1.5×10^{-3}	-3.2×10^{-5}	0.64	0.02

3. MAPPING THE 1-MIN RATES

The Tattelman-Scharr model was used to calculate 1-min rainfall rates exceeded 1.0, 0.50, 0.10, 0.05, and 0.01 percent of the time during the month (approximately 7.3 h, 3.6 h, 44 min, 22 min, and 4.4 min, respectively). Although the model can also be used to estimate rates exceeded 2 percent of the time in a

Table 3. Results of Stepwise Multiple Regression Analysis for Exceedance Levels p = 0.01, 0.05, 0.10, 0.50, 1.0, and 2.0 Percent Based on a Threshold Value of 1 mm for I. The regression coefficients are given for each independent variable

p	Constant (A_p)	T (B_p)	$I_{(1.00)}$ (C_p)	f(L,T) (D_p)	R	SEE (mm/min)
.01	-1.00	2.8×10^{-2}	3.6×10^{-2}	-2.2×10^{-4}	0.84	0.41
.05	-0.56	1.6×10^{-2}	2.5×10^{-2}	-2.4×10^{-4}	0.88	0.23
.10	-0.36	1.1×10^{-2}	2.0×10^{-2}	-2.4×10^{-4}	0.87	0.18
.50	-0.03	2.4×10^{-3}	7.8×10^{-3}	-1.2×10^{-4}	0.79	0.09
1.0	0.02	6.9×10^{-4}	4.2×10^{-3}	-6.2×10^{-5}	0.71	0.05
2.0	0.04	-1.8×10^{-4}	2.0×10^{-3}	-2.6×10^{-5}	0.67	0.02

Table 4. Results of Stepwise Multiple Regression Analysis for Exceedance Levels p = 0.01, 0.05, 0.10, 0.50, 1.0, and 2.0 Percent Based on a Threshold Value of 0.25 mm for I. The regression coefficients are given for each independent variable

p	Constant (A_p)	T (B_p)	$I_{(0.25)}$ (C_p)	f(L,T) (D_p)	R	SEE (mm/min)
.01	-1.00	2.8×10^{-2}	4.2×10^{-2}	$-2. \times 10^{-4}$	0.85	0.41
.05	-0.56	1.6×10^{-2}	3.0×10^{-2}	-2.3×10^{-4}	0.88	0.22
.10	-0.36	1.1×10^{-2}	2.4×10^{-2}	-2.3×10^{-4}	0.88	0.17
.50	-0.03	2.3×10^{-3}	1.0×10^{-2}	-1.2×10^{-4}	0.82	0.08
1.0	0.01	5.6×10^{-4}	6.0×10^{-3}	-5.6×10^{-5}	0.77	0.05
2.0	0.03	-2.3×10^{-4}	2.8×10^{-3}	-2.4×10^{-5}	0.74	0.02

month (approximately 14.5 h), these rates were not used for this atlas. A symbol representing a specified range of rates for each exceedance level at each location was then plotted on the AFGL equal-area map of the Northern Hemisphere used for this atlas. A publication by the USAF Environmental Technical Applications Center[6] was used to obtain model input data for most of the 3631 individual stations used for the Northern Hemisphere. Because this source does not contain data from

6. USAF Environmental Technical Application Center (1971) Worldwide Airfield Climatic Data, I-X; also published by U.S. Naval Weather Service as U.S. Naval Weather Service Worldwide Airfield Summaries.

Communist countries, data for 148 locations in these countries were obtained from a publication by the British Meteorological Office.[7] Data for a location were used only if the period-of-record was greater than 5 years. The spatial distribution of the locations used to make rate estimates is shown in Figure 1.

Tattelman and Scharr subjectively evaluated their model by estimating rates at independent locations representing a wide variety of the earth's climates. Results indicate circumstances when the model is either invalid or should be used with discretion. This occurred for very dry or cold months for which there were little or no data among the dependent stations. The model was found to be generally invalid when any of the following conditions existed for a specific month at a location:

(1) $T \leqslant 32°F (0°C)$

(2) $I < 2$ mm/day

(3) Number of rainy days < 1

Other model inconsistencies such as negative rates or increasing rates with increasing exceedance level (larger percent occurrence) occasionally occur when T is between 32°F and 40°F (0°C-4.4°C). Rates are very low when any of these conditions exist, and they fall into the lowest range of rates used for a plotting symbol at each exceedance level. Areas with < 1 rainy day per month are indicated on the charts.

At some locations, heavy but infrequent (1-3 rainy days) convective precipitation accounts for virtually all of the precipitation in one or more months. Under these circumstances, the model may estimate rates for each of the six exceedance levels which, when integrated, result in a total rainfall much greater than the monthly mean precipitation. To deal with this, a coarse estimate of the monthly precipitation based on the estimated rates at each location was made using the algorithm

$$\hat{P} = R_{.01} \times t_{.01} + \frac{R_{.01}+R_{.05}}{2}\left(t_{.05}-t_{.01}\right) + \frac{R_{.05}+R_{.10}}{2} \times \left(t_{.10}-t_{.05}\right) + \cdots \frac{R_{1.0}+R_{2.0}}{2}\left(t_{2.0}-t_{1.0}\right) \tag{3}$$

where $\hat{P}$ = the estimated total monthly precipitation,

R_p = the rate estimated for exceedance probability (p), and

t = the number of min per month at each exceedance probability.

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7. Meteorological Office (1966) Tables of Temperature, Relative Humidity and Precipitation for the World, Part I-VII, Her Majesty's Stationery Office, London.

Locations where the estimated monthly precipitation calculated from Eq (3) exceeded 4 times the observed mean monthly precipitation were identified to aid in the analysis. This is discussed in Section 4. A factor of 4 was subjectively chosen for this check on model estimates after examining results for locations representing a variety of the earth's rainfall regimes.

4. METHODS USED TO ANALYZE THE MAPS

Rainfall-rate estimates for each location were assigned a symbol representing a specified range of rates at each exceedance level. For p = 0.01, 0.05, 0.10, 0.50, and 1.0 percent of the time, ranges of 0.20, 0.15, 0.10, 0.10, and 0.05 mm/min respectively were used. These ranges also represent the intervals between isolines for the analysis at each exceedance level. For example, on the analysis for p = 0.01 percent, if the estimated rate was between 0 and 0.199 mm/min, a specific symbol/color was printed on the map for that location. If the rate was between 0.20 and 0.399 mm/min, another symbol/color was used, and the isoline representing the boundary between the two was labeled 0.20 mm/min.

The analyses of Northern Hemisphere charts for four mid-season months at each of five exceedance levels (p = 0.01, 0.05, 0.10, 0.50, 1.0 percent of the month) are provided in Figures 2-21. Rate estimates for all 12 calendar months were scanned to develop maps of the highest 1-min rainfall rates at each exceedance level regardless of the month in which they occurred. These are provided for each of the five exceedance levels in Figures 22, 24, 26, 28, and 30. Companion charts showing the month of the year in which the highest 1-min rates occurred for each exceedance level are provided in Figures 23, 25, 27, 29, and 31.

Figure 1 shows that the density of stations used for the analyses is quite low in some areas. In these regions, such as Asia and northern South America, a greater degree of subjectivity in placing the isolines was necessary. Because of the absence of data, there are no isolines in Saudi Arabia, eastern Somalia, and in South America near the equator. In mountainous terrain, rates varied considerably between nearby stations as a result of differences in elevation and/or exposure to sources of moisture. Consequently, elevations generally greater than about 1500 m are hatched on the maps, and isolines are dashed in these areas to indicate their uncertain validity. The dashed isolines are usually truncated and then resumed elsewhere at the edge of the mountainous area, indicating either lack of data or extreme variability of rates. Dashed lines outside of hatched mountainous areas indicate a greater degree of subjectivity and hence uncertainty in the analysis. Dashed lines are used over water to connect isolines over adjacent land areas. All isolines over water areas reflect data from locations on land, and should not be considered an accurate analysis of rainfall rates over the water surface.

Locations where the model is not valid for estimating rates because there is less than one rainy day in the month are bounded by a line of alternating dashes and dots. These areas are frequently surrounded by regions with one to three rainy days for which rate estimates may be high (see Section 3). Therefore, rain-rate isolines were subjectively adjusted in the vicinity of locations for which the estimated monthly precipitation from Eq (3) exceeded 4 times the observed monthly precipitation.

Either rain-rate gradients in some areas and months were too large to show all the isolines or there were insufficient data to depict the true gradient in the analysis. This problem was most common in the tropics, especially south of the Sahara Desert and eastward to southeastern Asia. For example, high rainfall rates occur in equatorial Africa much of the year, but the Sahara Desert just to the north commonly has less than one rainy day per month. In these circumstances, isolines are either eliminated or truncated.

For islands or island groups/chains, a value representing the middle of the range is shown if there is only one station with a rate estimate. Where there are two or more stations with estimates, the values of the bottom of the lowest range and the top of the highest range are shown.

In comparison to the mid-season charts, the most objective analyses are the charts of the highest 1-min rainfall rates at each exceedance probability regardless of the month in which they occurred (Figures 22, 24, 26, 28, and 30). The reasons for this are:

(1) There are a greater number of stations with valid data.
(2) Rate estimates for any month at a location were used only if the estimated monthly precipitation calculated from Eq (3) did not exceed 4 times the observed mean monthly precipitation.
(3) Rain-rate gradients are not as extreme.

5. MAP DISCUSSION

5.1 January (Figures 2-6)

As shown in Figures 2-6, rates are generally low during January, and only a few small areas north of 40°N latitude have rates exceeding 0.2 mm/min 0.01 percent of the time. India eastward to Cambodia and much of Africa average less than one rainy day during the month. Highest rates, exceeding 1.6 mm/min 0.01 percent of the month, occur in the southern Philippines, in parts of Indonesia, in Sri Lanka, on some south Pacific islands, and in parts of South America. In some areas, especially equatorial Africa and southern India eastward to southeast Asia, there are strong gradients between high rates and dry areas with less than one rainy day.

5.2 April (Figures 7-11)

As shown in Figures 7-11, most of the tropical areas south of 10° N latitude have rates exceeding 1.6 mm/min 0.01 percent of the time during April, with the highest rates exceeding 2.2 mm/min over a large portion of Indonesia. There are strong gradients between these areas and dry areas (< 1 rainy day) covering a large part of Africa eastward to northwestern India. Rates are minimal in most continental areas north of 45 N latitude.

5.3 July (Figures 12-16)

As shown in Figures 12-16, the highest rates during July occur in coastal equatorial Africa in the vicinity of Liberia, along the coast of southwestern India, along the coast from eastern India to Burma, in western Indonesia, along the southern coast of China, and in the Philippines. Rates in these areas range from 2.0 to more than 2.2 mm/min 0.01 percent of the time. On the other hand, very dry regions (< 1 rainy day) can be found in the southwestern United States and in a large area from northern Africa eastward to Afghanistan and western Pakistan.

5.4 October (Figures 17-21)

As shown in Figures 17-21, highest rates during October occur in southern India, Sri Lanka, and in parts of Vietnam and the Philippines. Rates in these areas exceed 2.0 mm/min 0.01 percent of the time. A large belt of very dry conditions stretches across interior Africa eastward to western India. Rates are minimal in most continental areas north of 50° N latitude.

5.5 Worst Month (Figures 22,24,26,28, and 30)

As shown in Figures 22, 24, 26, 28, and 30, the highest rates during the most severe month generally occur in southeastern Asia from India eastward to the Philippines. Rates in most of this area exceed 2.0 mm/min 0.01 percent of the time, with rates exceeding 2.4 mm/min in some regions. Rates in parts of this area exceed 0.2 mm/min 1 percent of the time during the most severe month. Similarly high rates occur on the west coast of Africa in the vicinity of Liberia. The highest rates in the contiguous United States occur in southwestern Florida, where rates exceed 1.8 mm/min 0.01 percent of the time, and 0.1 mm/min 1 percent of the time during the most severe month. It is notable that a large portion of the interior of northern Africa does not average as much as one rainy day in any month of the year.

5.6 Month With the Highest Rates (Figures 23,25,27,29, and 31)

As shown in Figures 23, 25, 27, 29, and 31, the highest rates occurring 0.01 percent of the time generally occur during the summer months (June-August), with July being the most severe month over most of North America, Asia, and eastern Europe. The most severe month varies considerably in tropical areas, especially south of 20°N latitude. At greater percentages of occurrence, the most severe month is more difficult to generalize, and there is considerable variability of months with highest rates exceeded 1 percent of the time.

6. CONCLUSIONS

The model used to develop this atlas uses long term climatic data (> 5 years) as input. Therefore, rain-rate estimates are considered to represent a long-term average. These may not be adequate for design problems for which a low risk is important, since year-to-year variations in the distribution of 1-min rates observed at a specific location can be quite large.

The charts presented herein are intended to present the spatial distribution of 1-min rainfall rates in the hemisphere. However, it should be noted that the analyses required a substantial amount of subjectivity, as discussed in Section 4, and smoothing of the isolines was necessary in areas with large local variations in rates. Therefore, it would be more appropriate to use the Tattelman-Scharr model when rate estimates for a particular location are required and when the climatic input data are available.

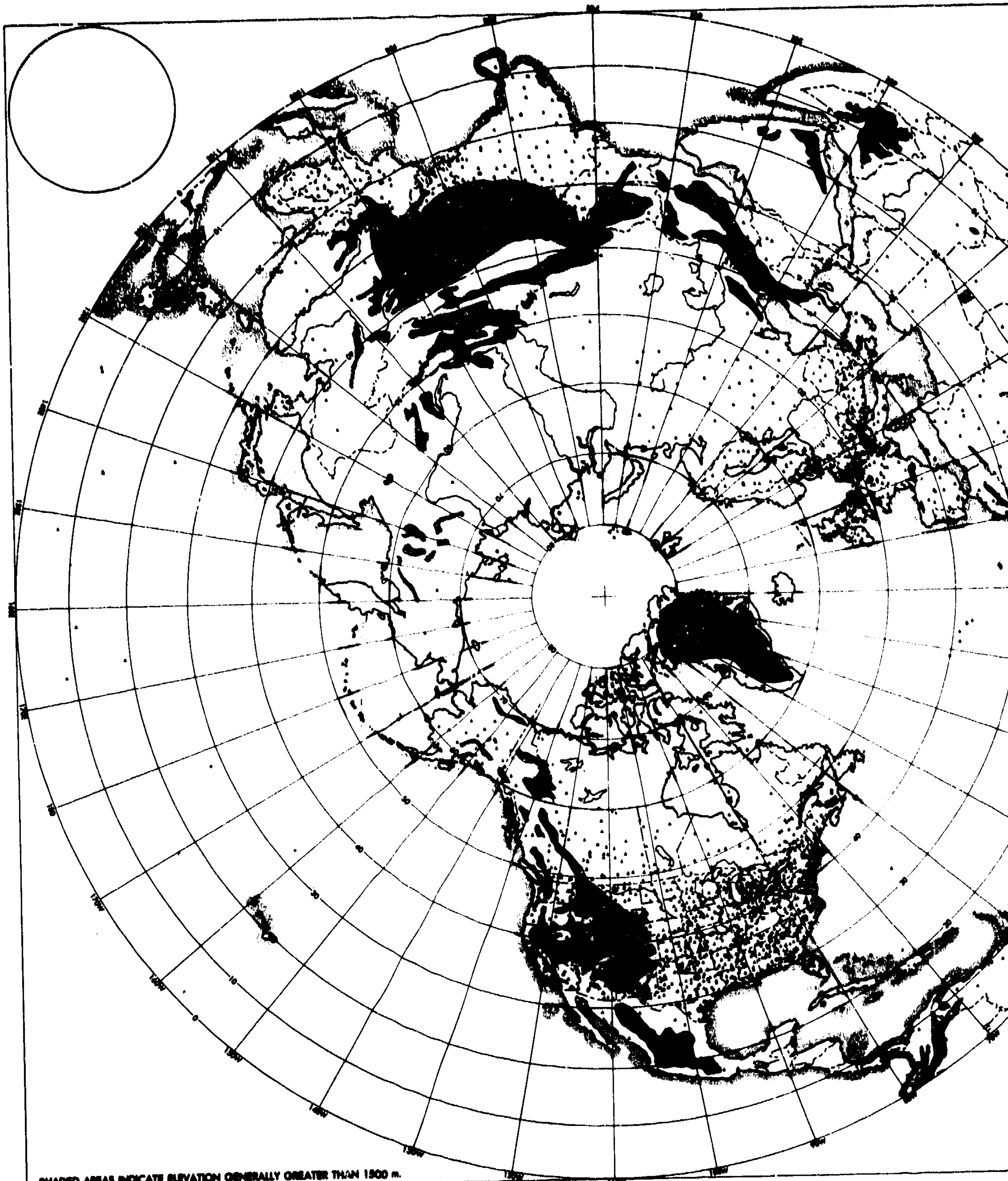
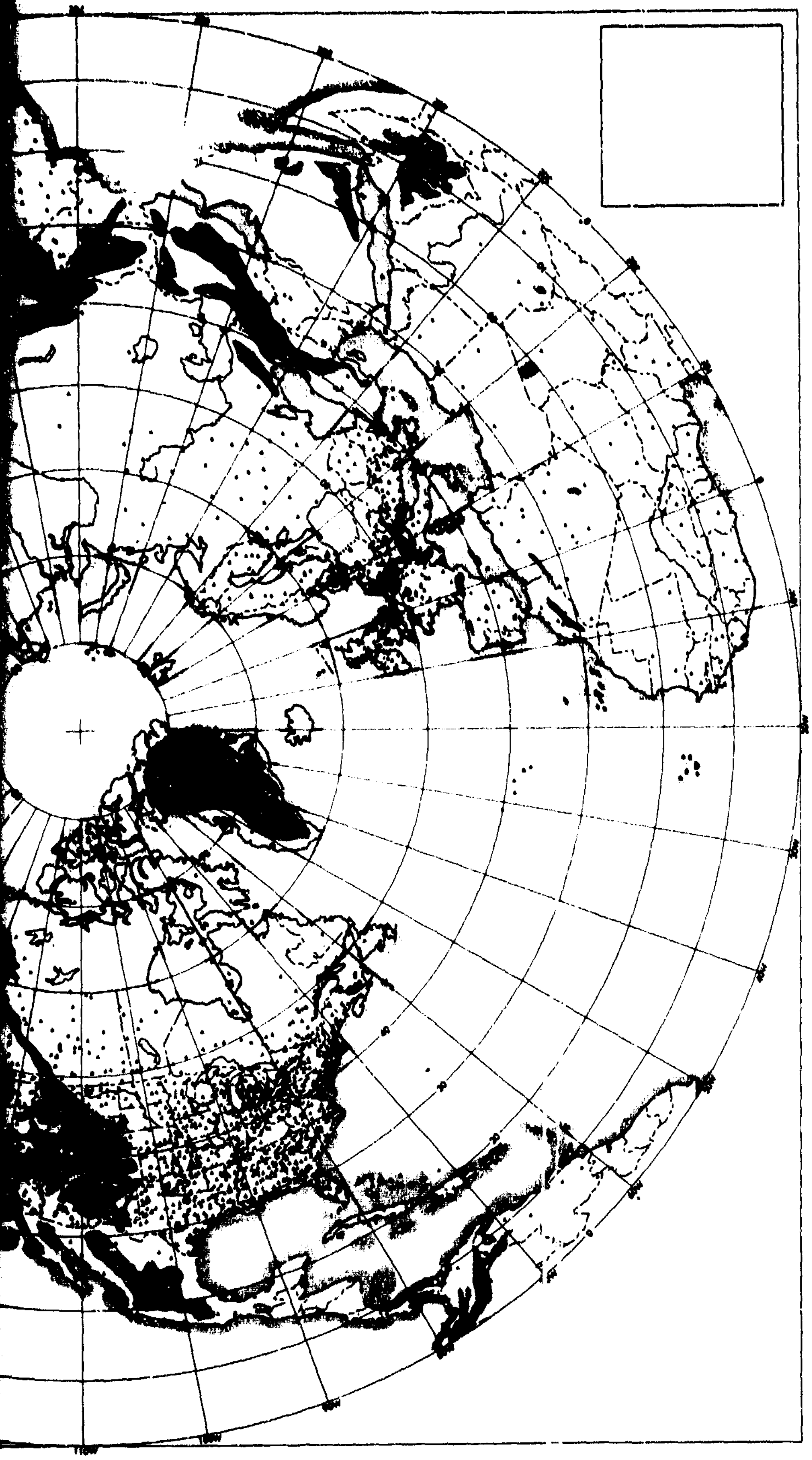


Figure 1. Spatial Distribution of Locations for Which Data Were Used

2



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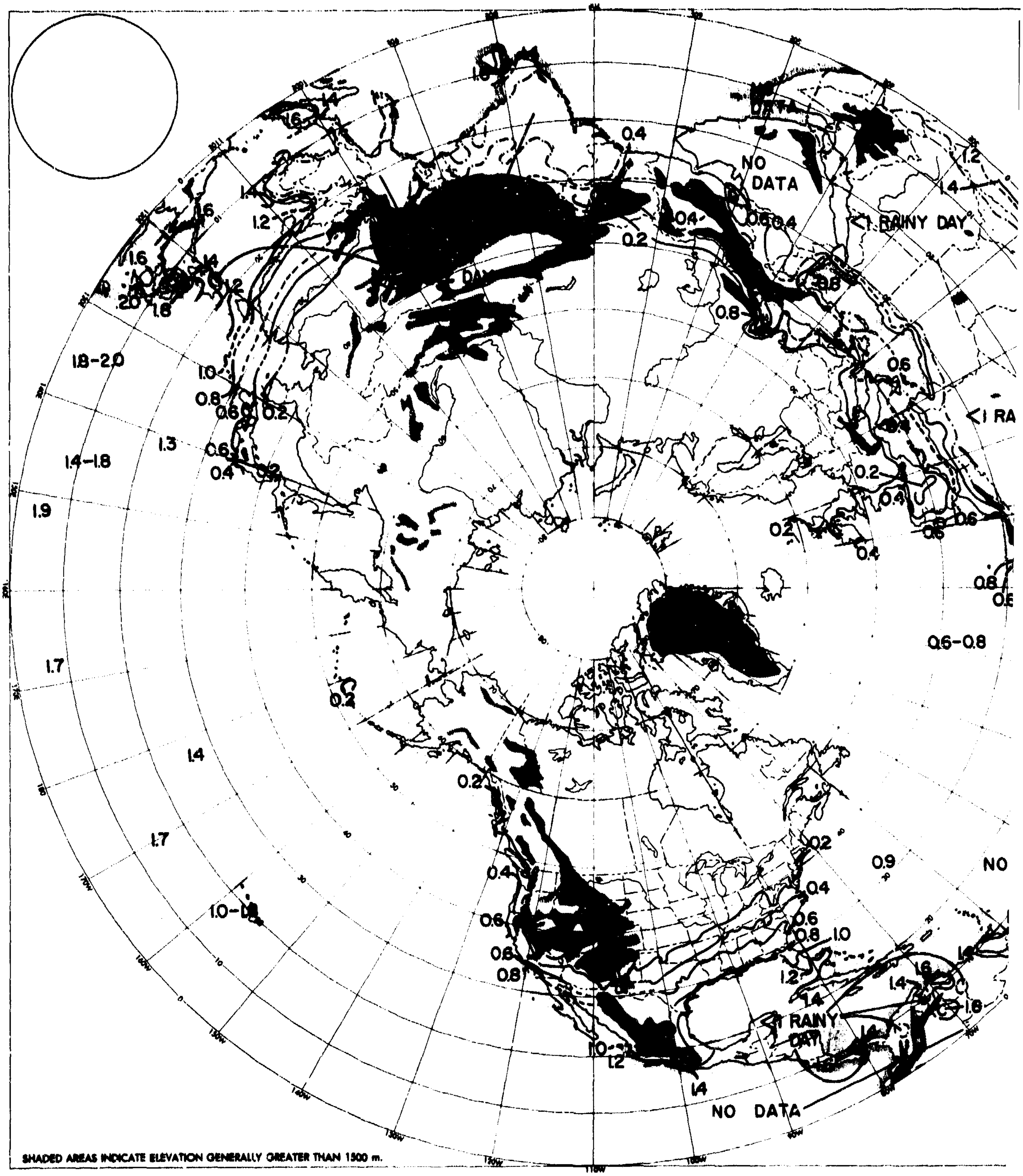

Figure 2. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 0.01 Percent of the Time in January

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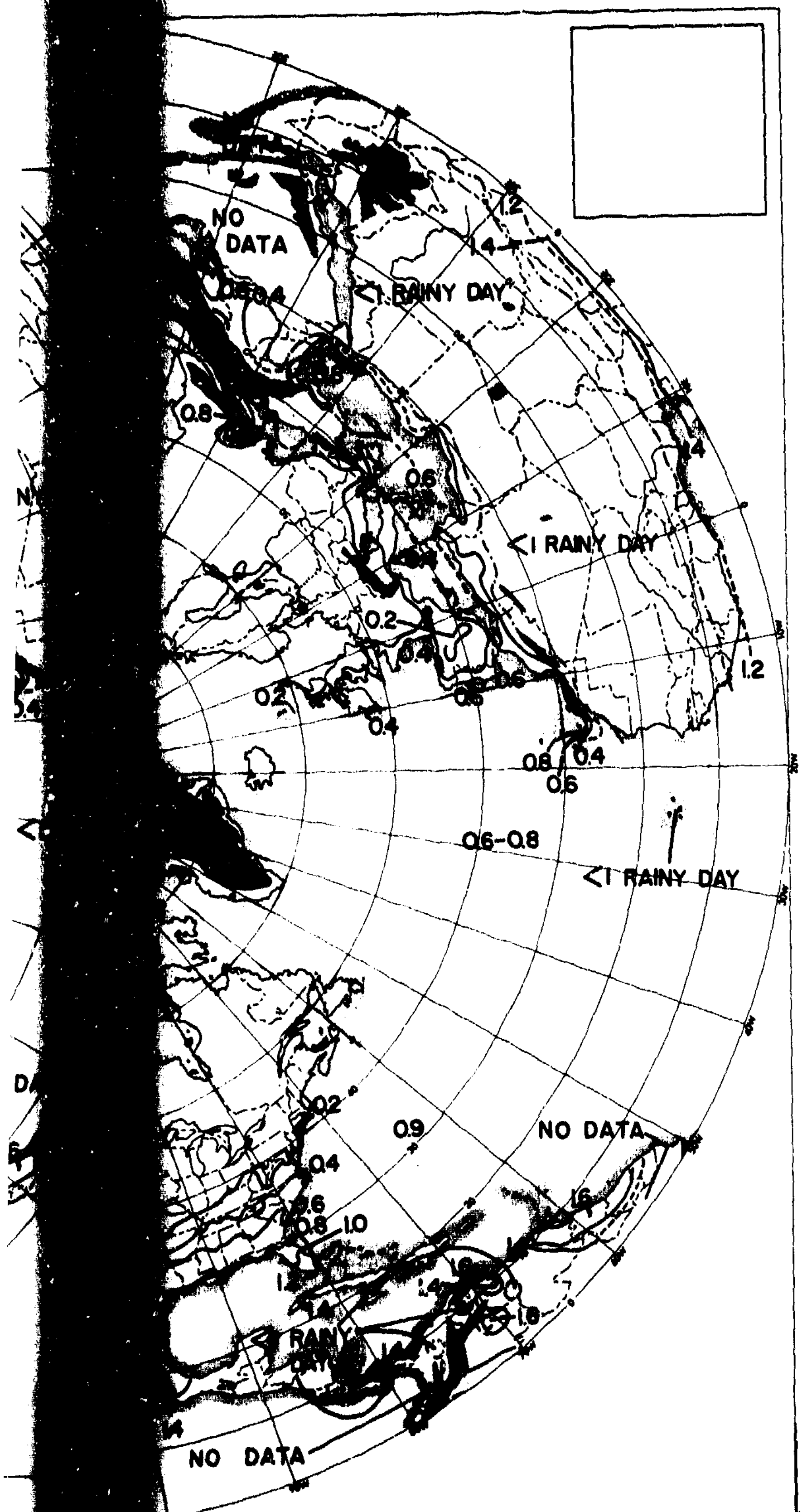
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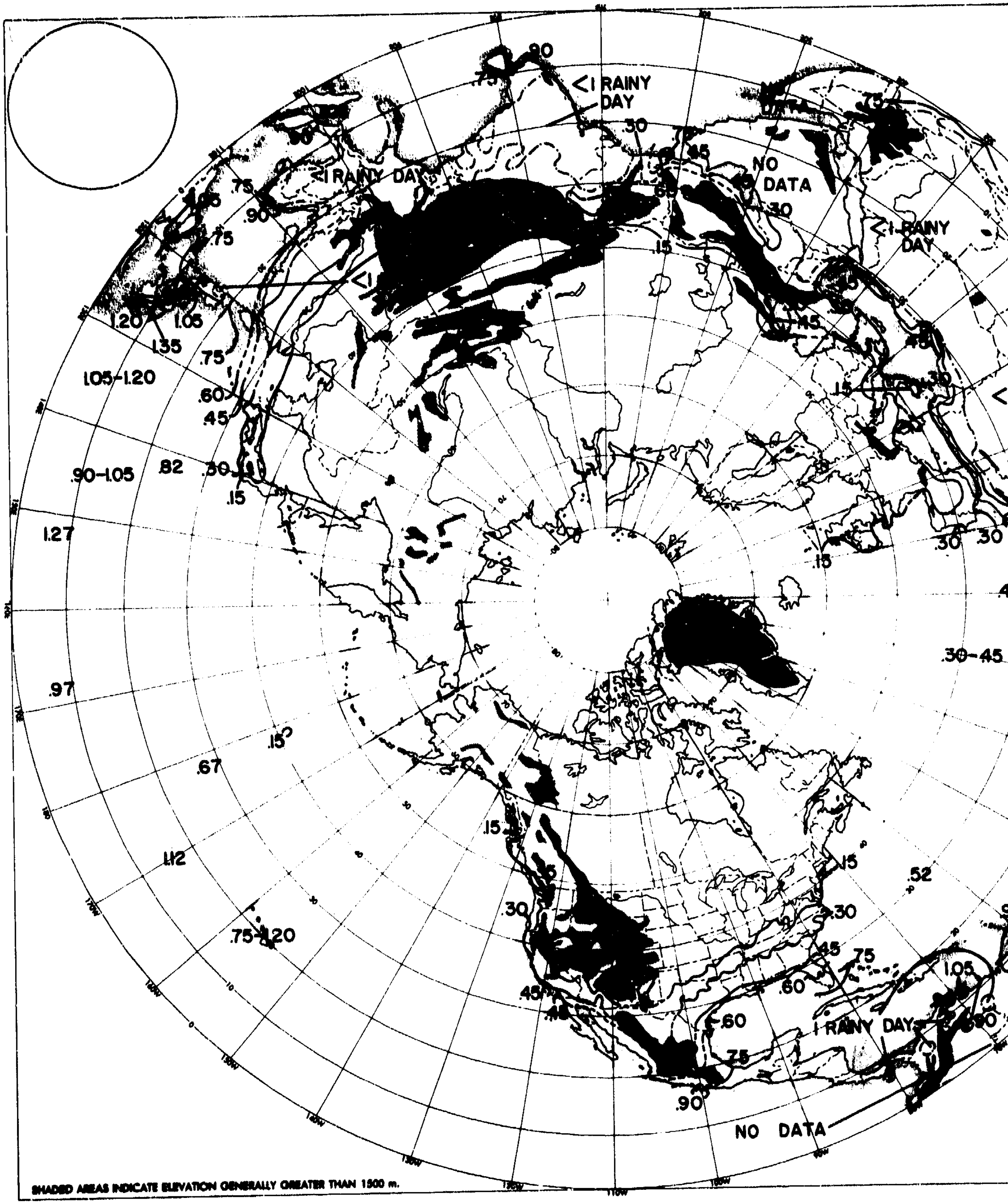
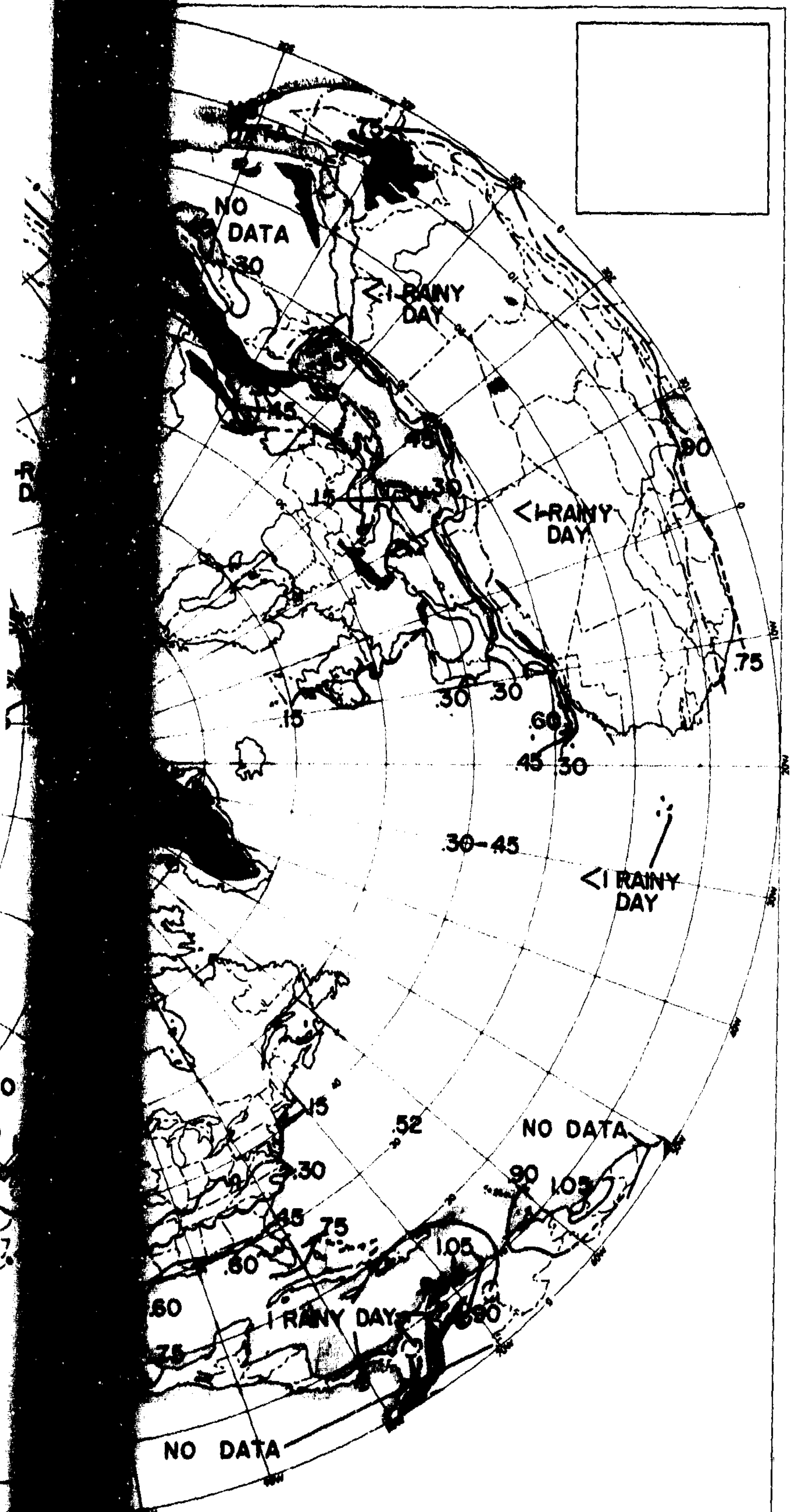


Figure 3. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 0.50 Percent of the Time in January

2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<1 RAINY
DAY
.90
.75
.30
.30
.15
.60
.45
.30
.30-45
<1 RAINY
DAY
.15
.52
NO DATA
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1.05
.30
.45
.75
.80
1.05
.60
1 RAINY DAY
.90
.75
NO DATA

ent of

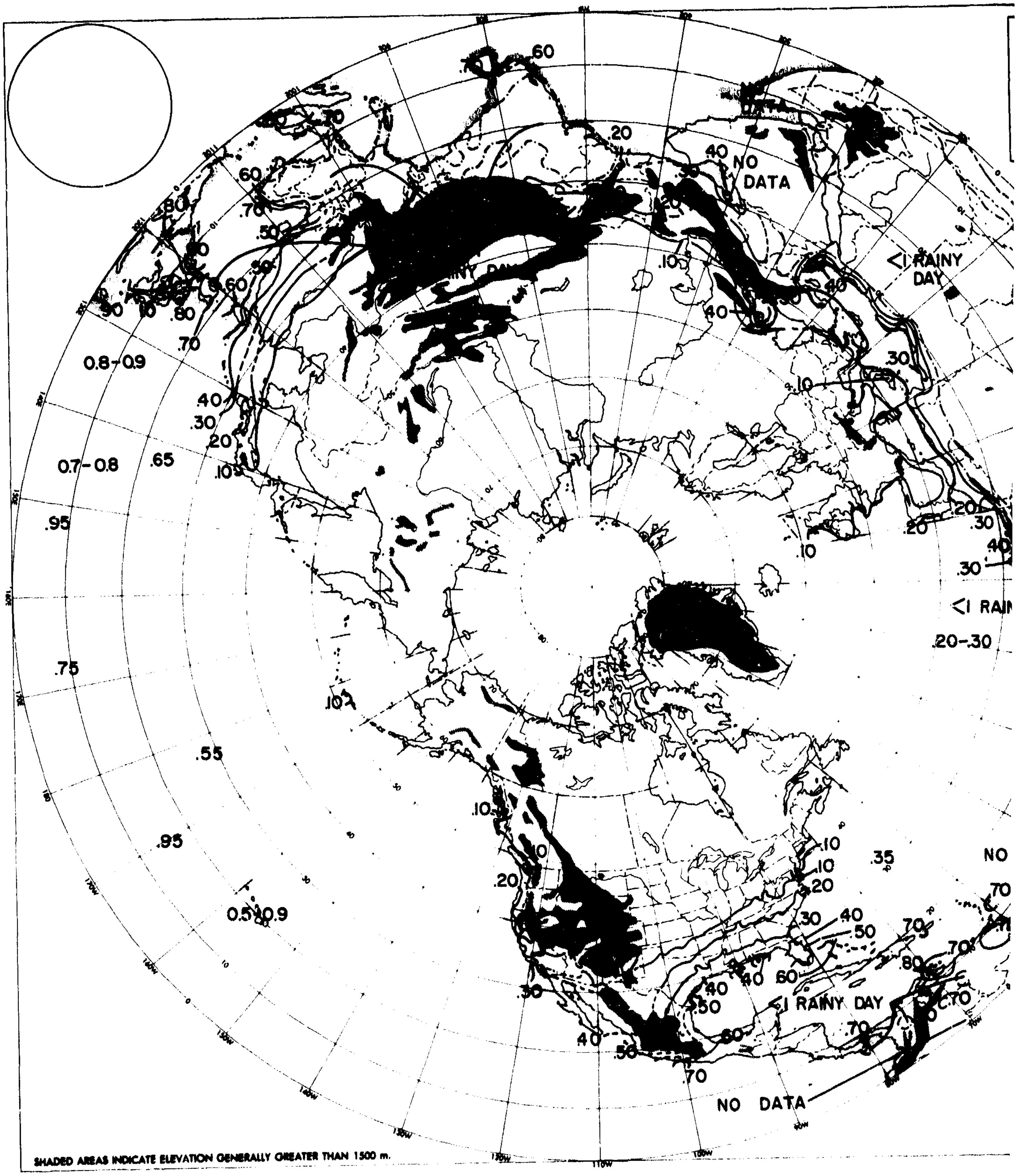
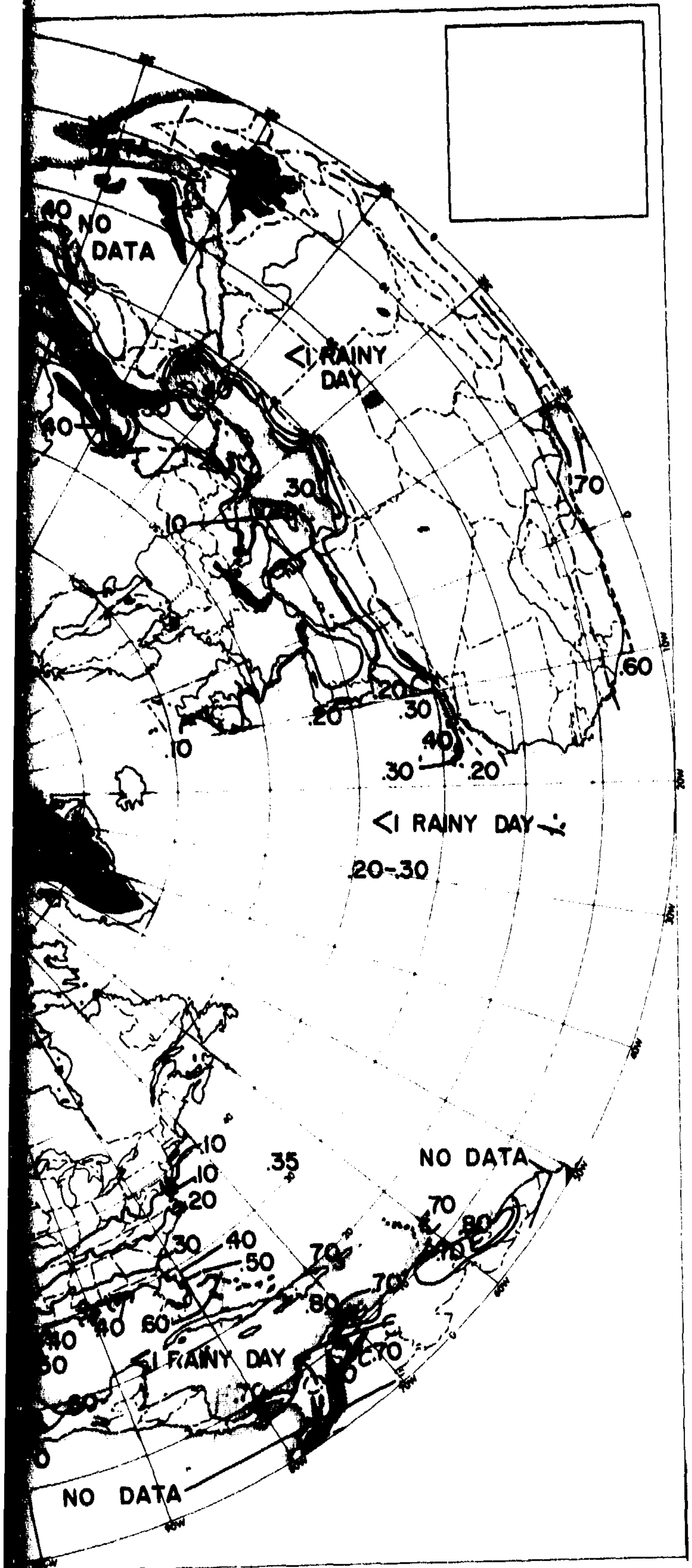


Figure 4. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 0.10 Percent of the Time in January

2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.20
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.10
.10
.35
.20
NO DATA
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.80
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.40
.50
.70
.70
.80
.60
.40
<1 RAINY DAY
C.70
NO DATA

ent of

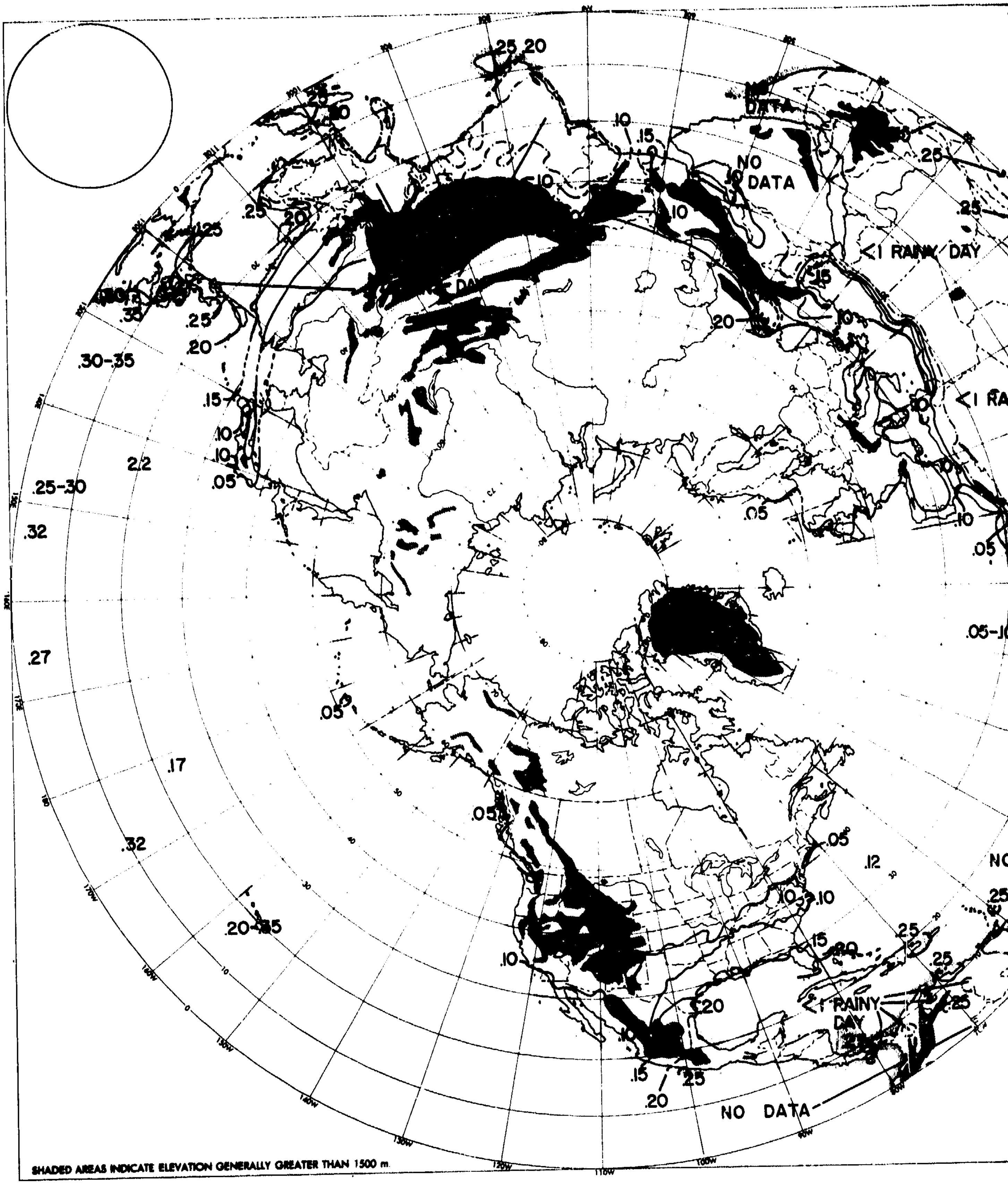
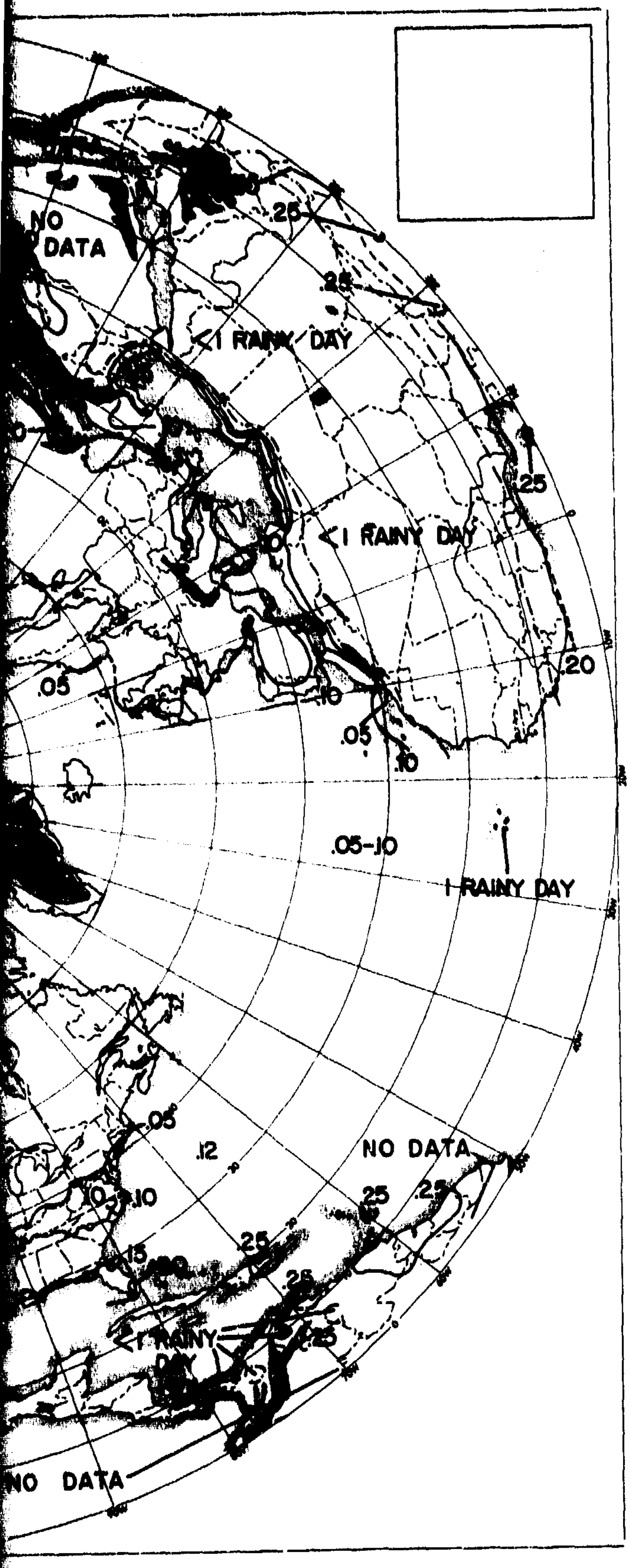


Figure 5. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 0.50 Percent of the Time in January

2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.25
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.25
.10
<1 RAINY DAY
.20
.05
.10
.05
.10
.05-.10
1 RAINY DAY
.05
.12
NO DATA
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.25
.10
.10
.25
.15
.20
.25
<1 RAINY DAY
.25
NO DATA

of

1

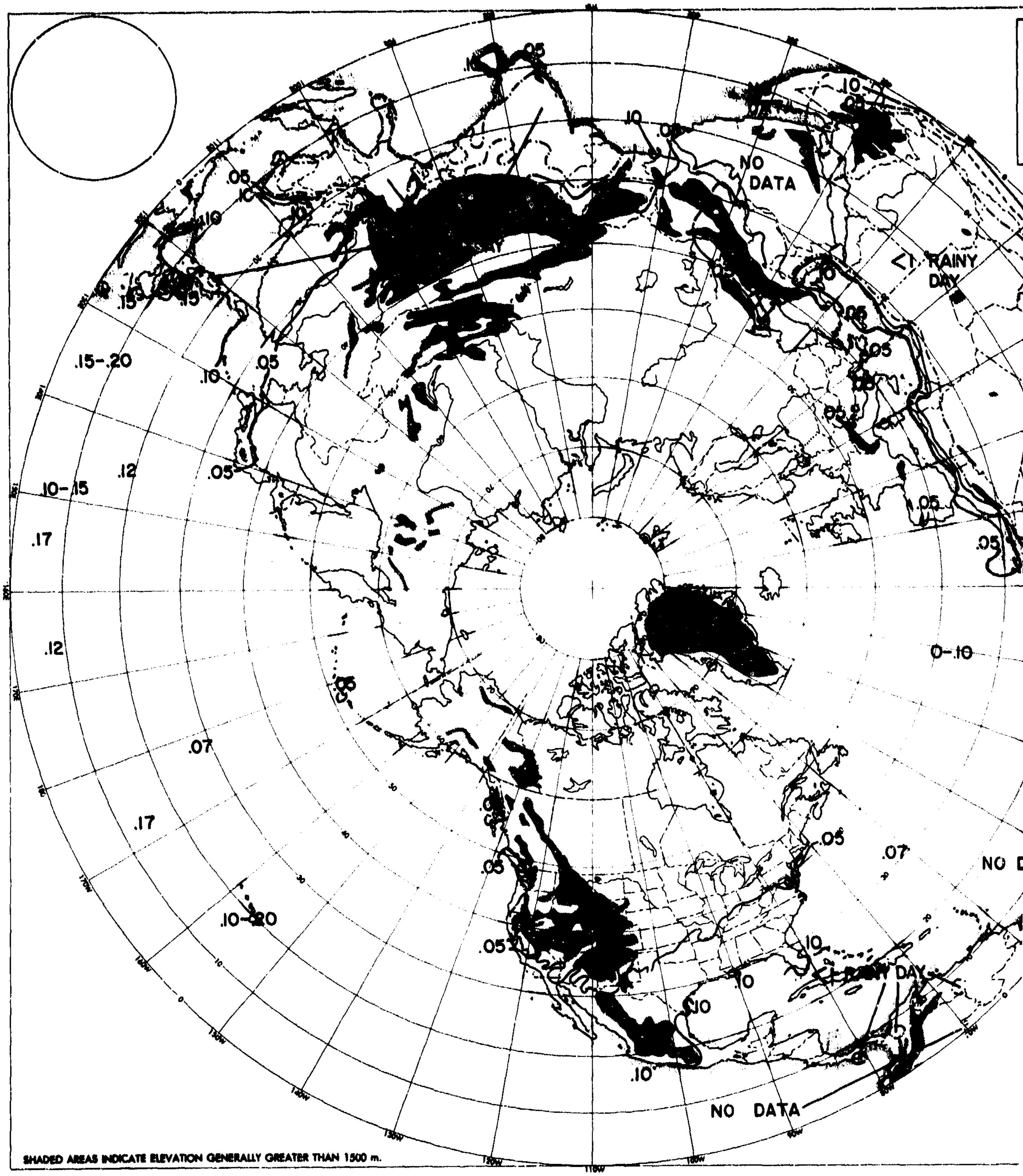

Figure 6. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 1.0 Percent of the Time in January

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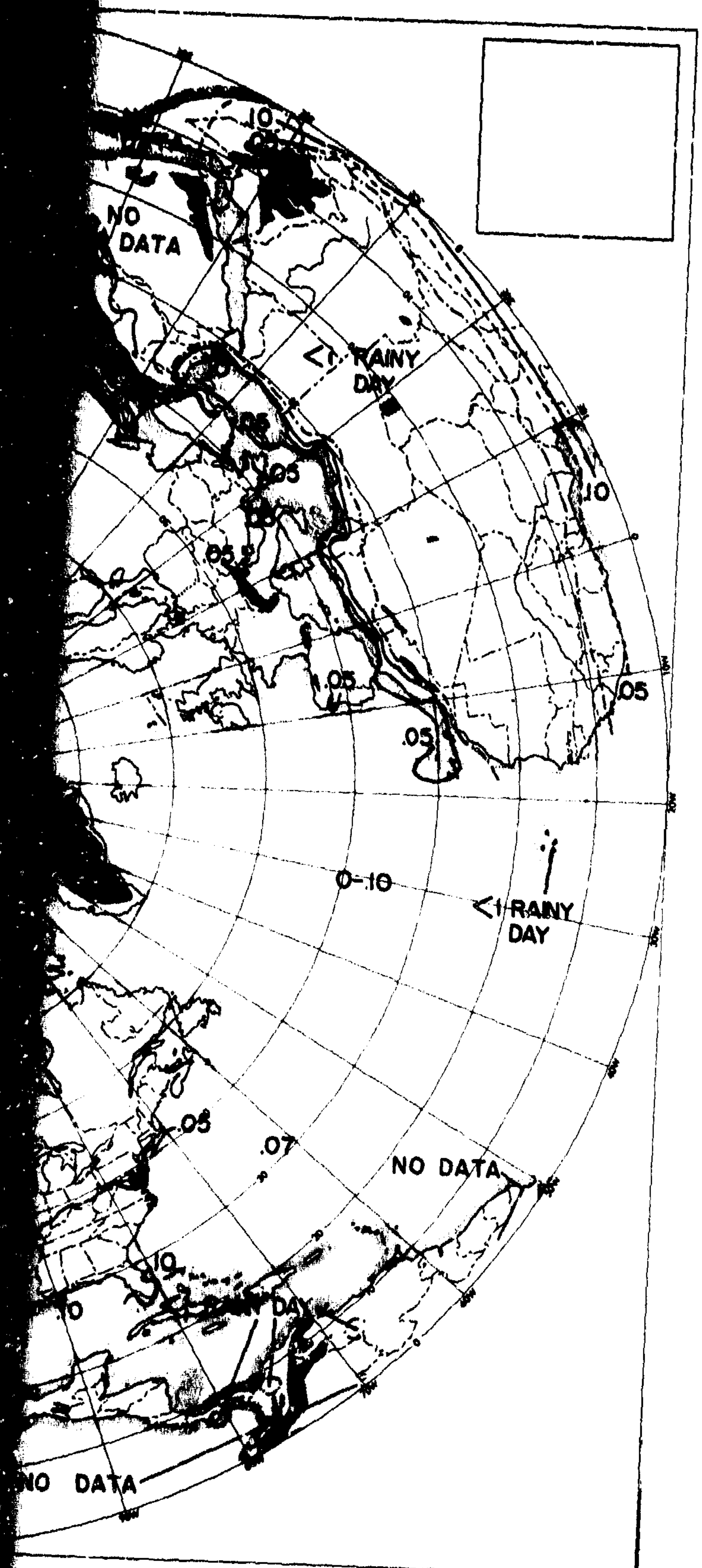
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.05
.10
.05
.05
.05
0-.10
<1 RAINY DAY
.05
.07
NO DATA
.10
RAINY DAY
NO DATA

of

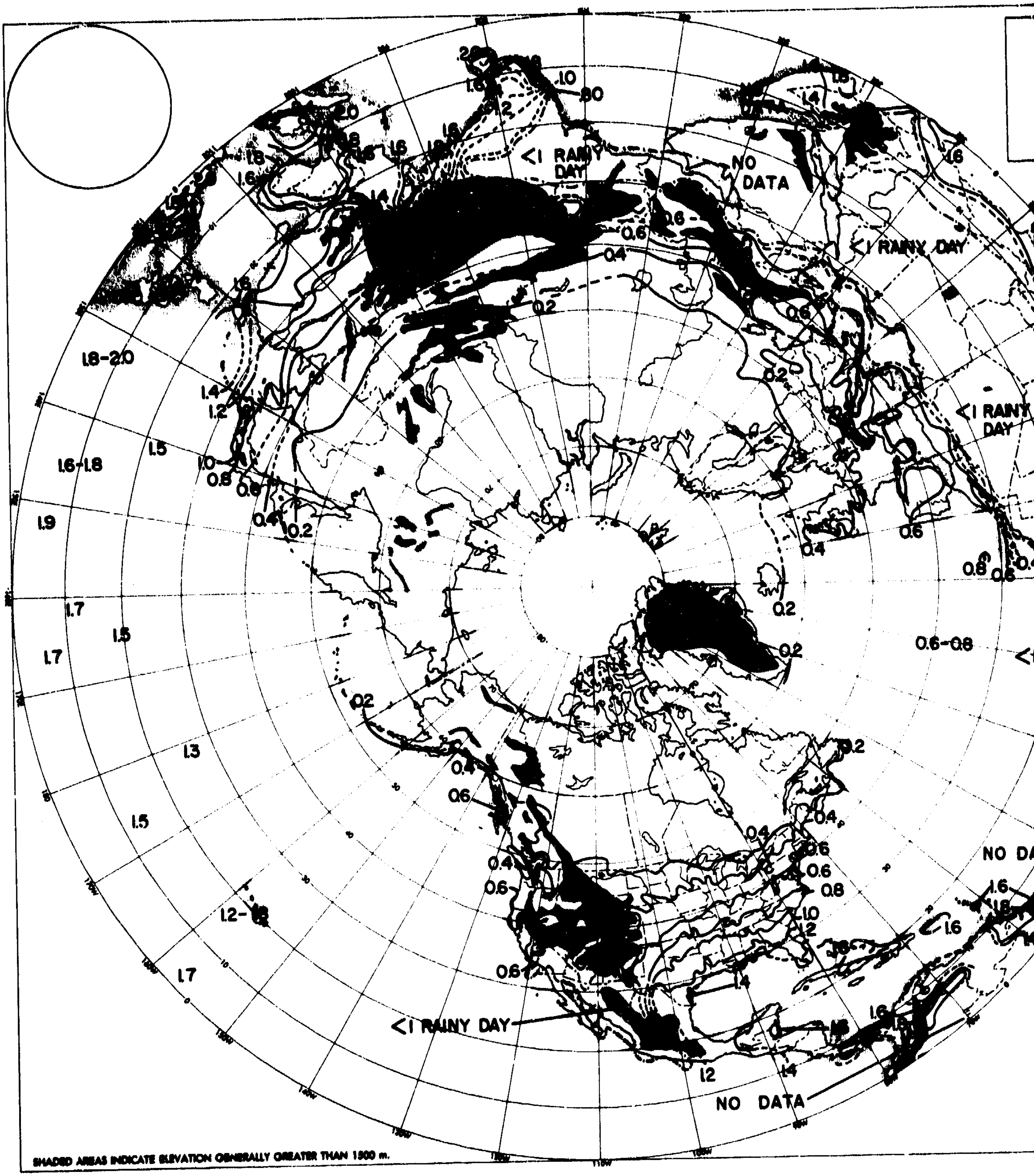
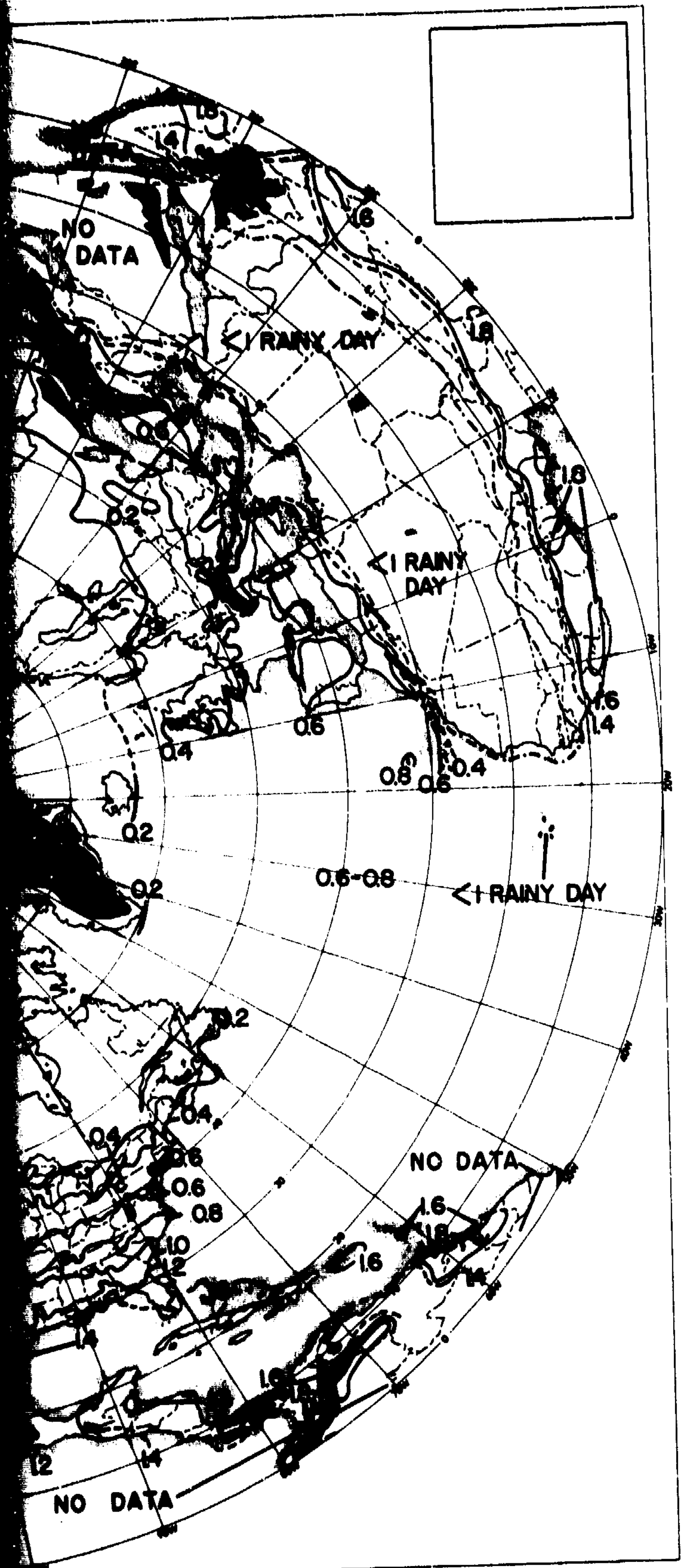


Figure 7. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 0.01 Percent of the Time in April

2


NO DATA
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<1 RAINY DAY
<1 RAINY DAY
0.6-0.8
NO DATA
NO DATA
1.8
1.6
1.4
0.6
0.4
0.2
0.8

ent of

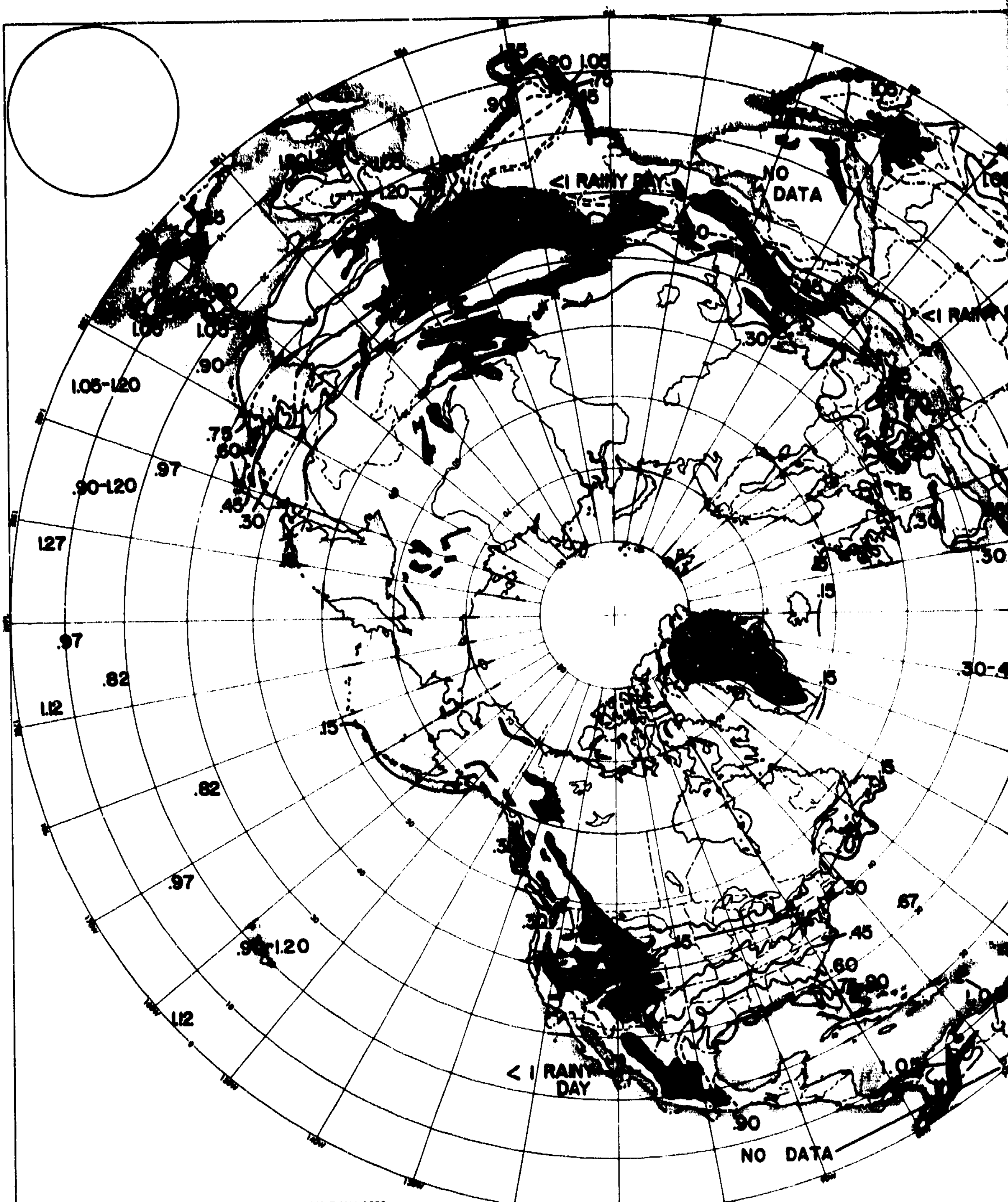
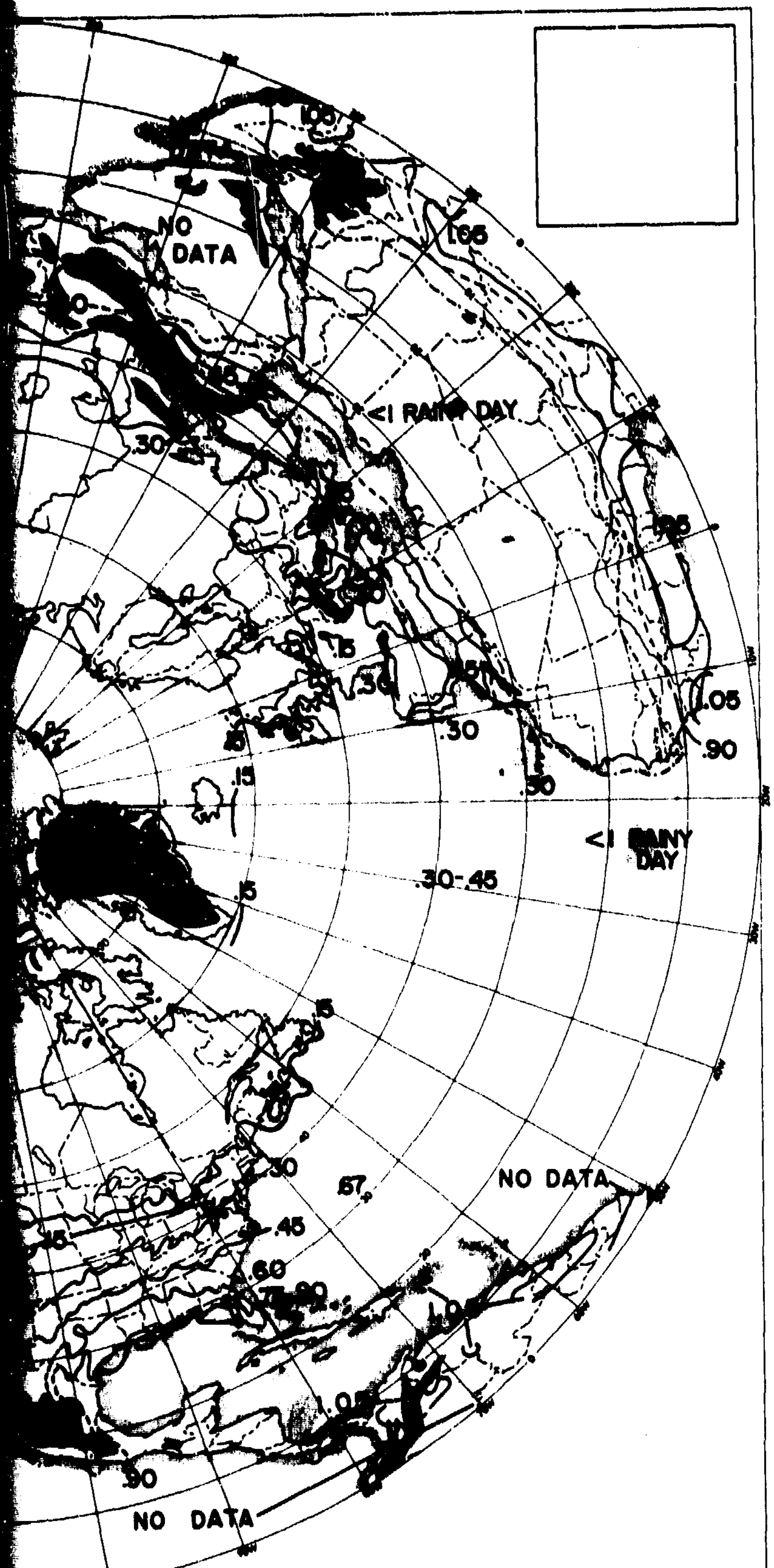


Figure 8. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 0.05 Percent of the Time in April

2



5 Percent of

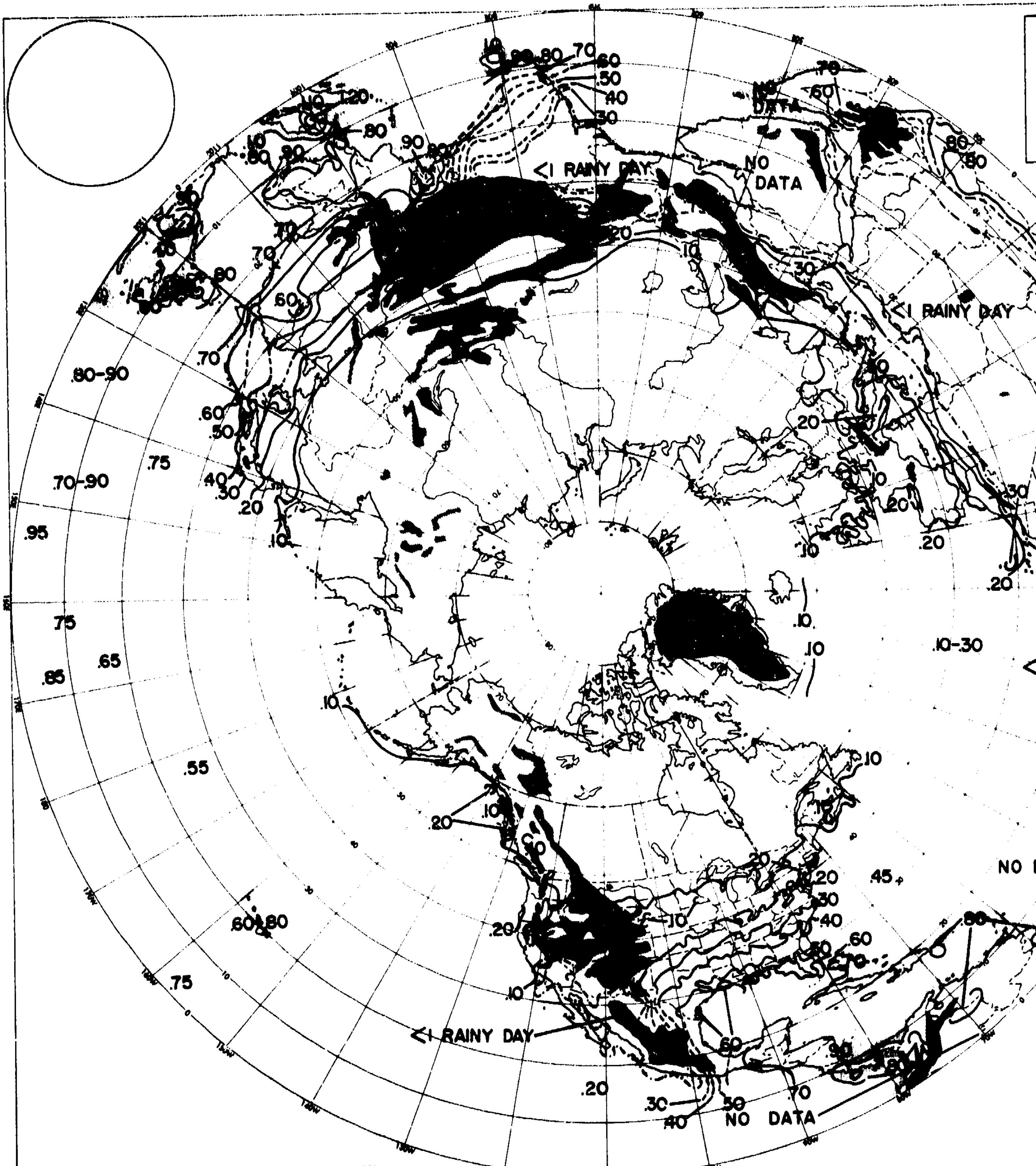
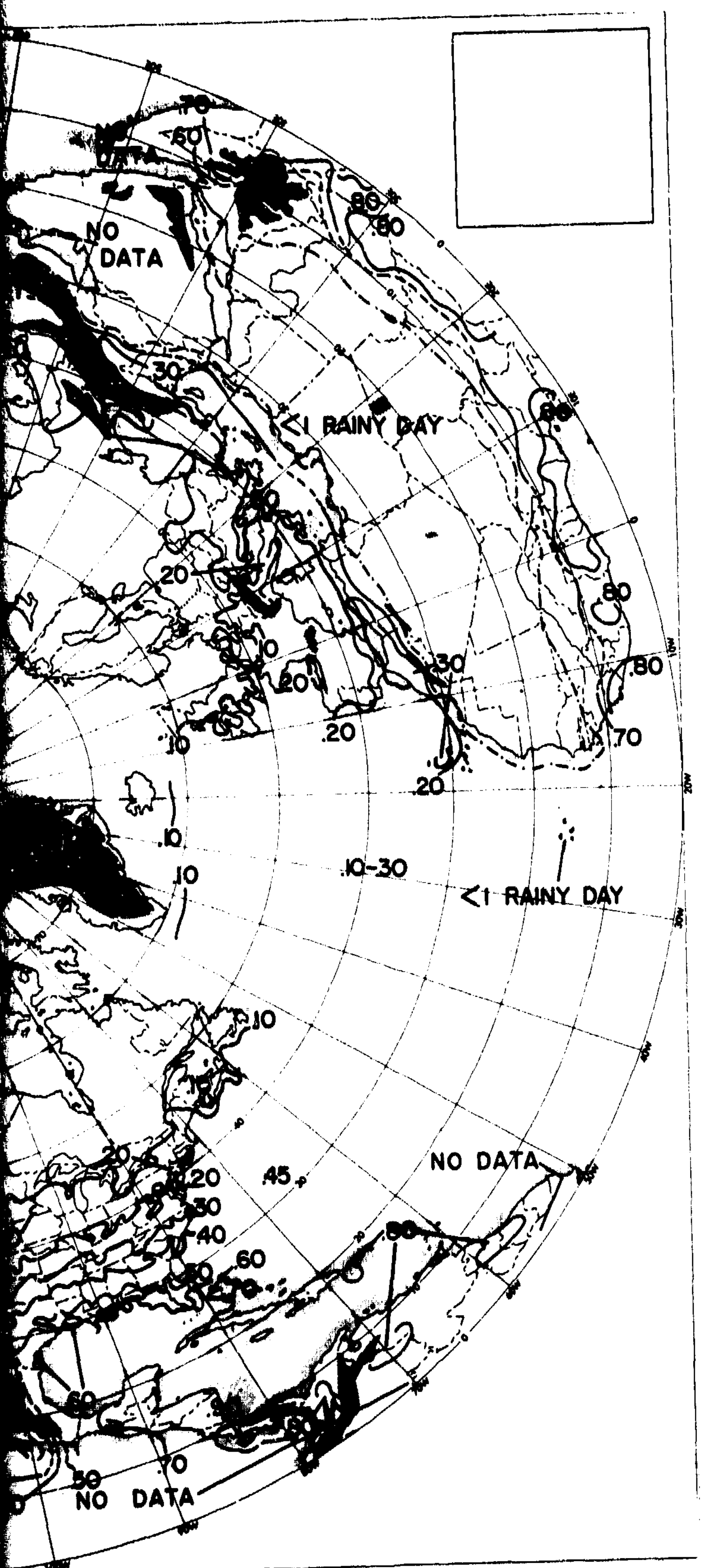


Figure 9. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 0.10 Percent of the Time in April

2



NO DATA
70
60
80
30
<1 RAINY DAY
20
10
.20
.10
.10-30
<1 RAINY DAY
.70
.80
45
20
30
40
50
60
NO DATA

ercent of

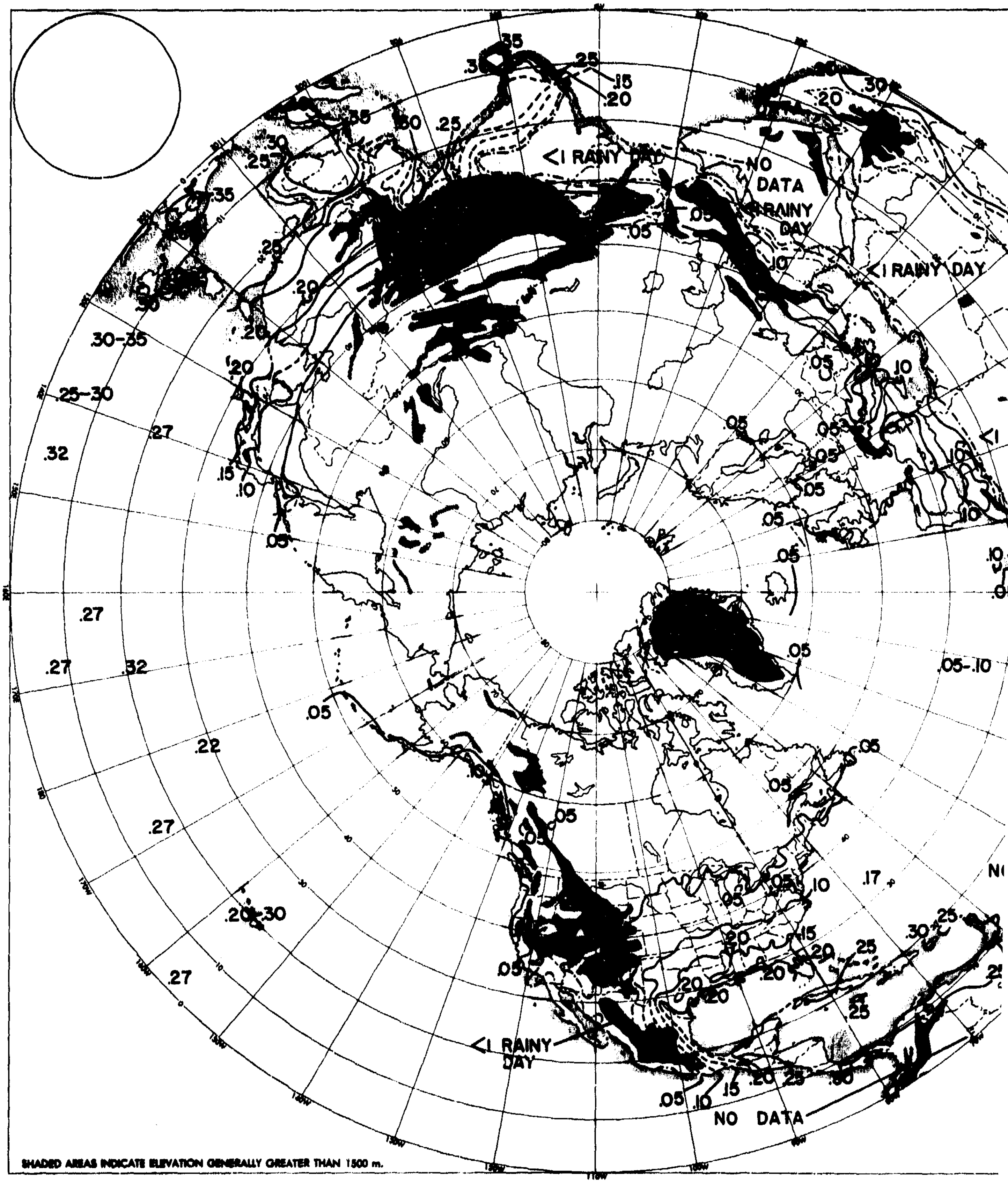
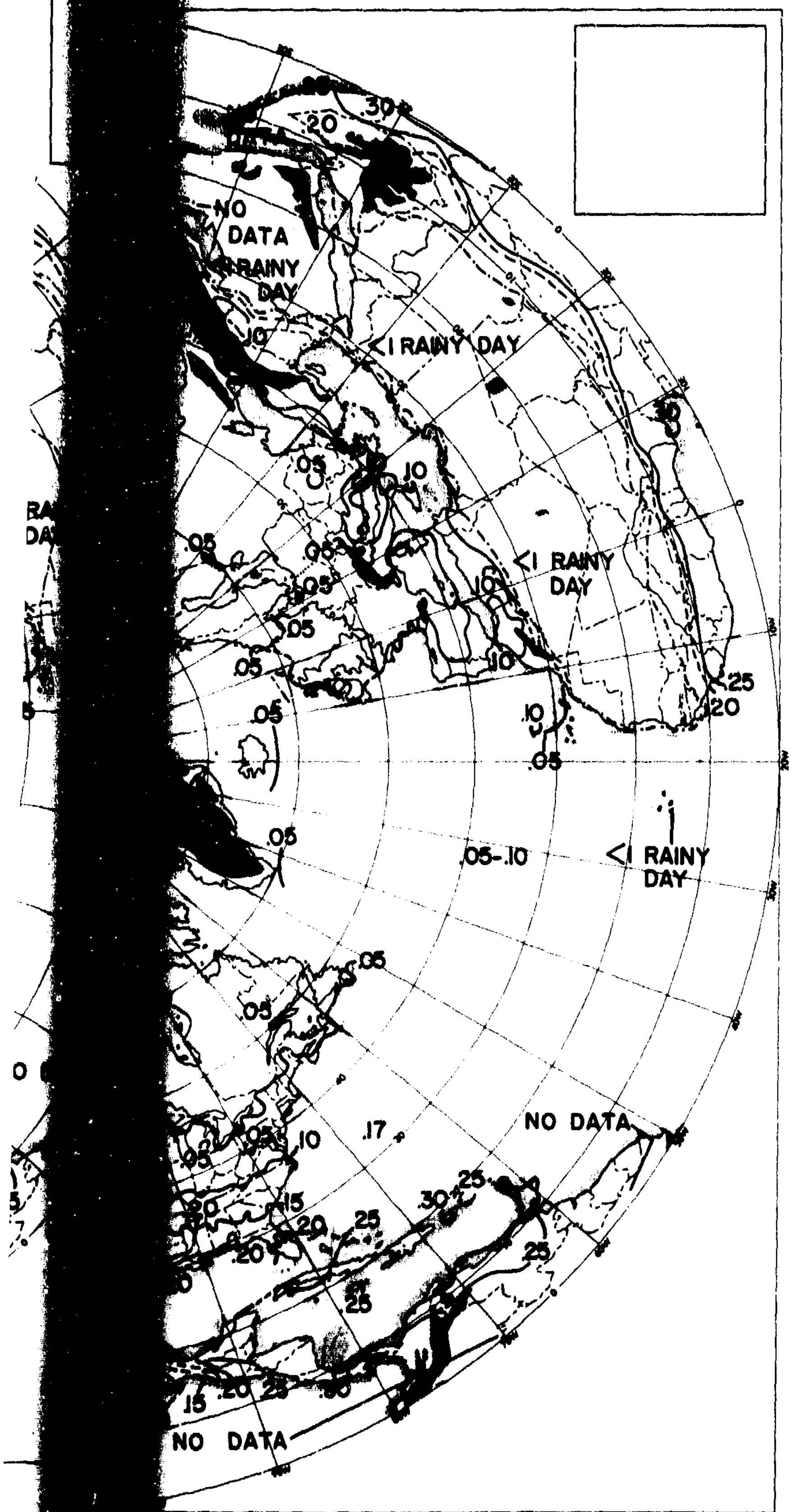


Figure 10. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 0.50 Percent of the Time in April

2



NO DATA
RAINY DAY
<I RAINY DAY
<I RAINY DAY
<I RAINY DAY
.05-.10
NO DATA
NO DATA

ent

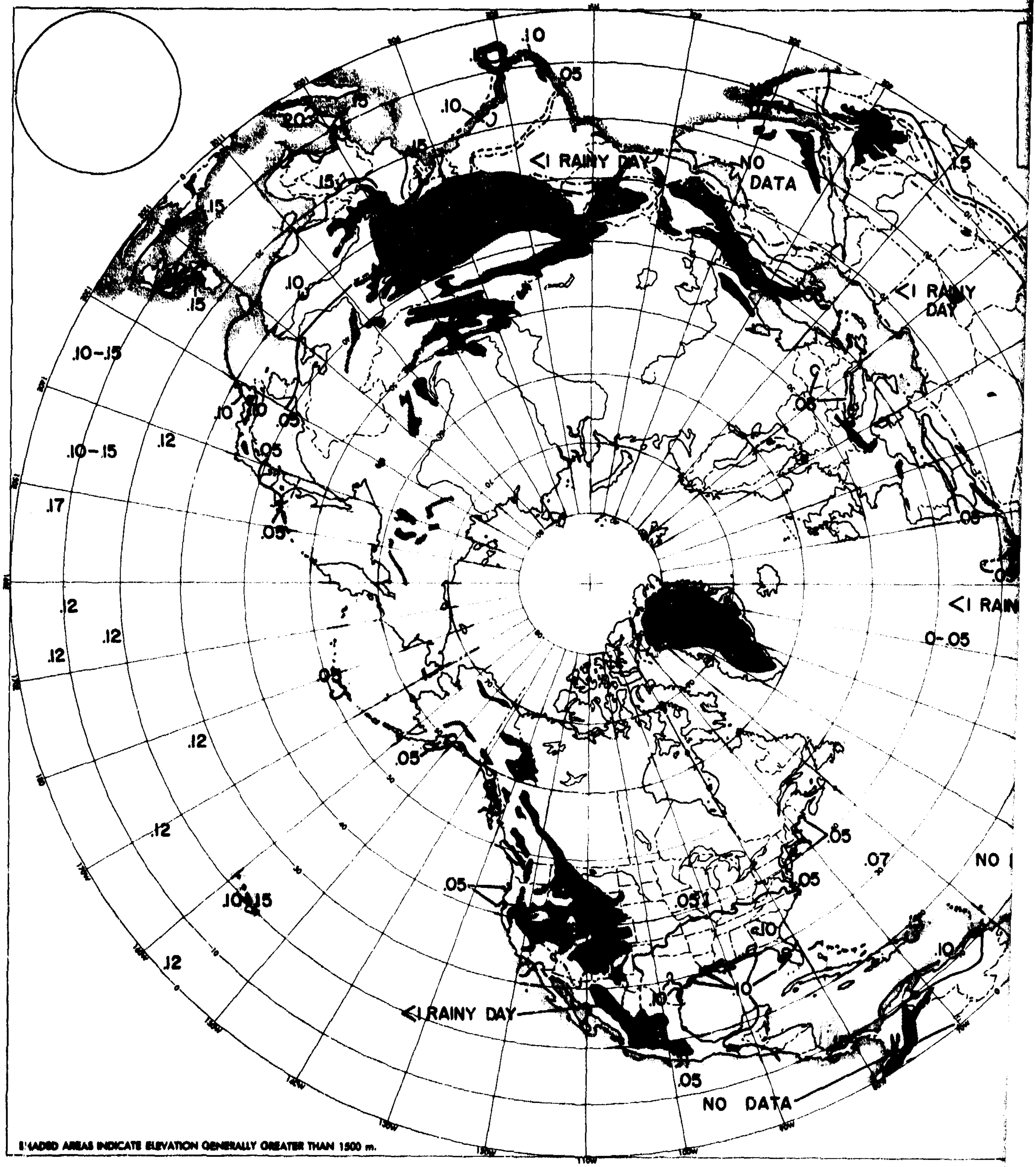
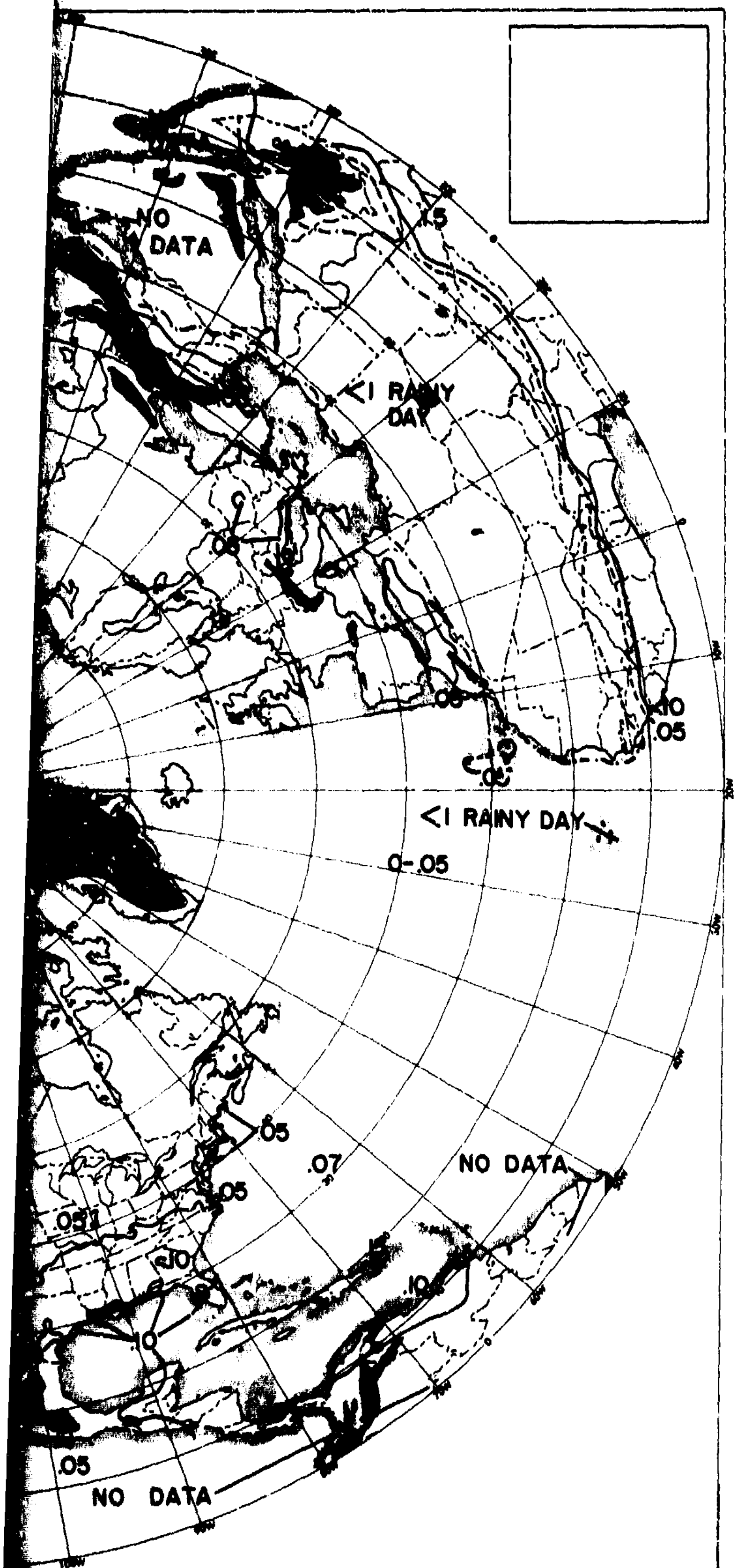


Figure 11. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 1.0 Percent of the Time in April

2


NO DATA
.5
<I RAINY DAY
.05
.10
.05
<I RAINY DAY
0-.05
.05
.07
NO DATA
.05
.10
.10
.10
.05
NO DATA

ercent of

1

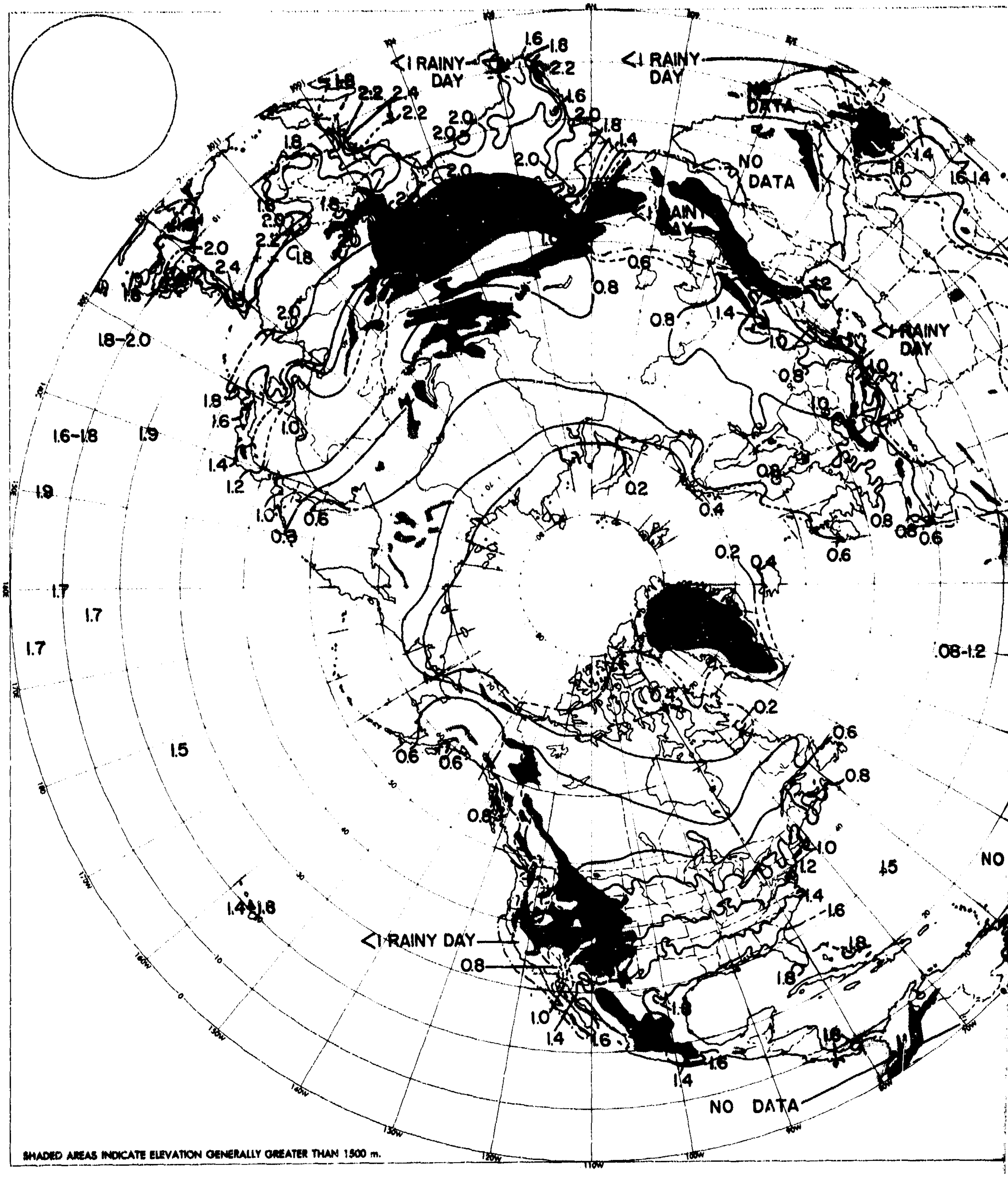
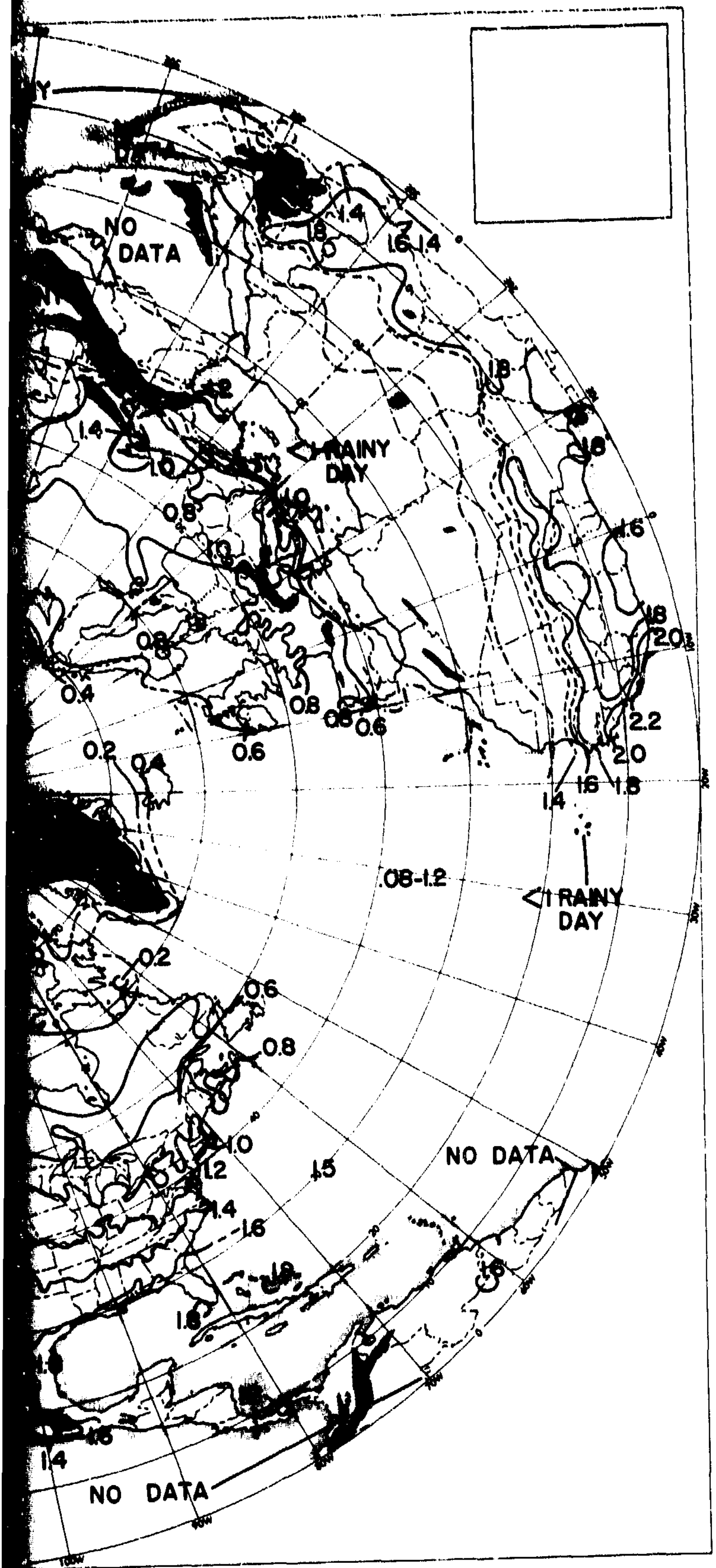


Figure 12. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 0.01 Percent of the Time in July

2



ercent

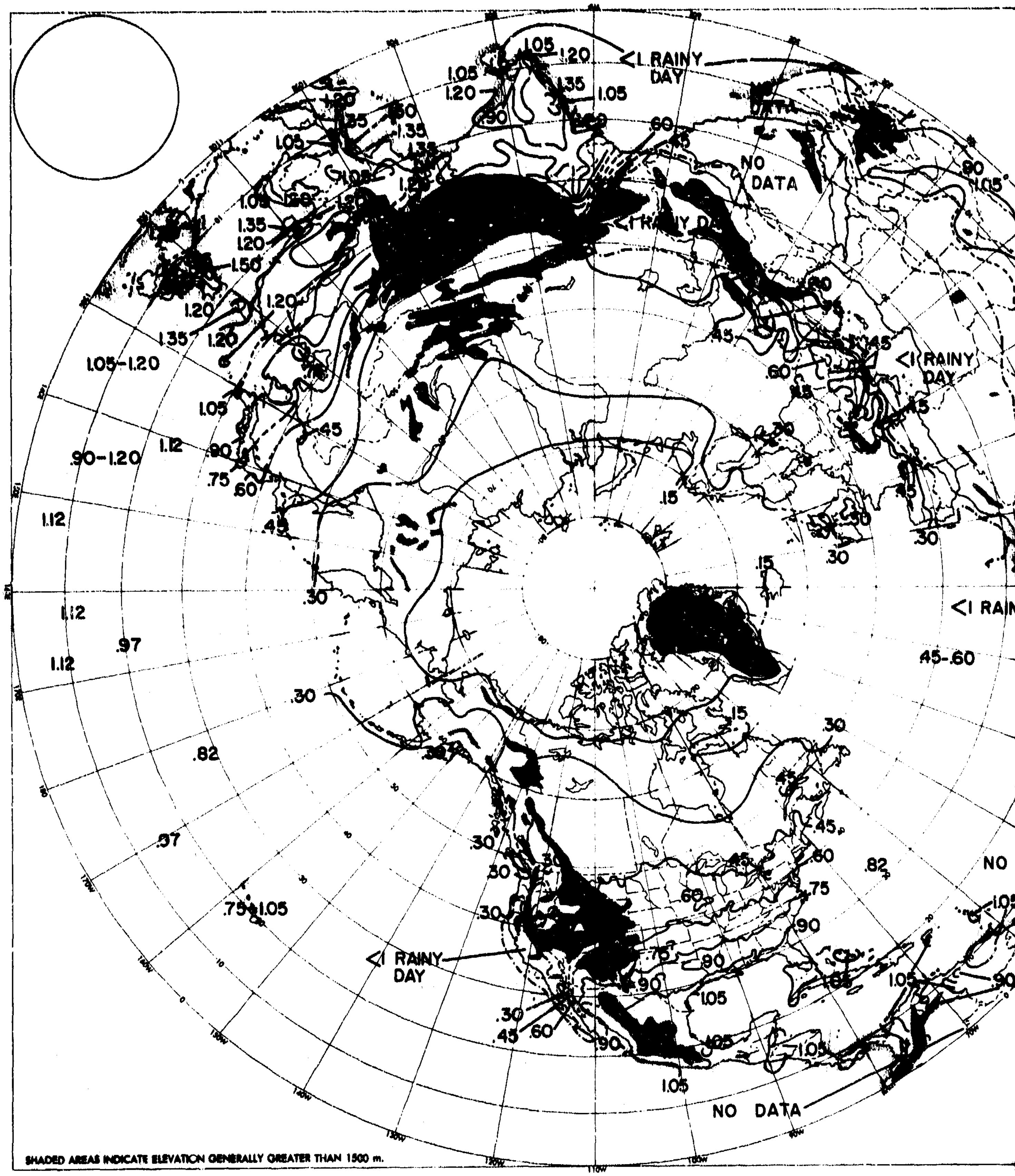
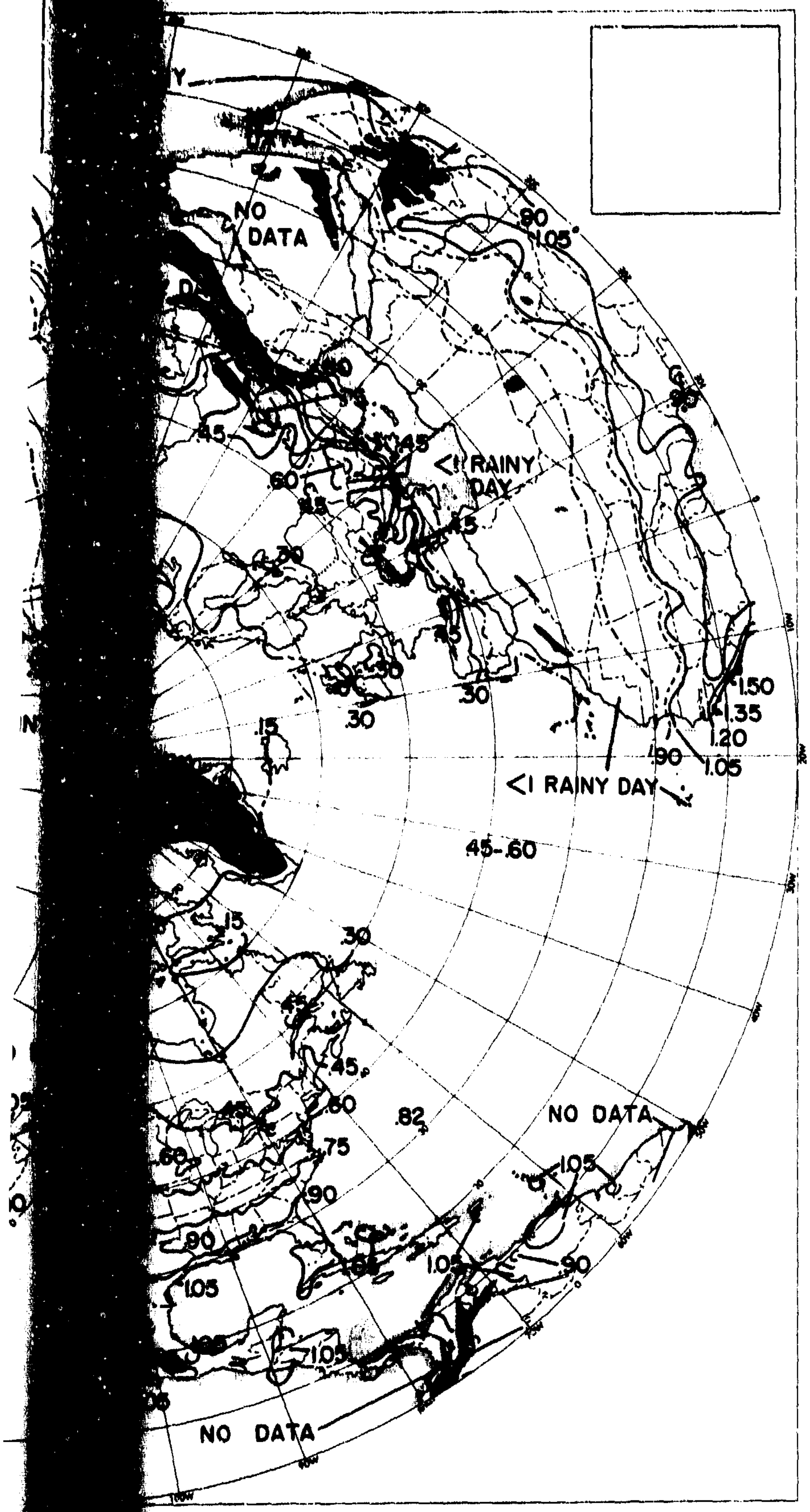


Figure 13. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 0.05 Percent of the Time in July

2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<1 RAINY DAY
<1 RAINY DAY
45-.60
NO DATA
NO DATA
1.50
1.35
1.20
1.05
.90
.30
.15
.82
.75

ercent

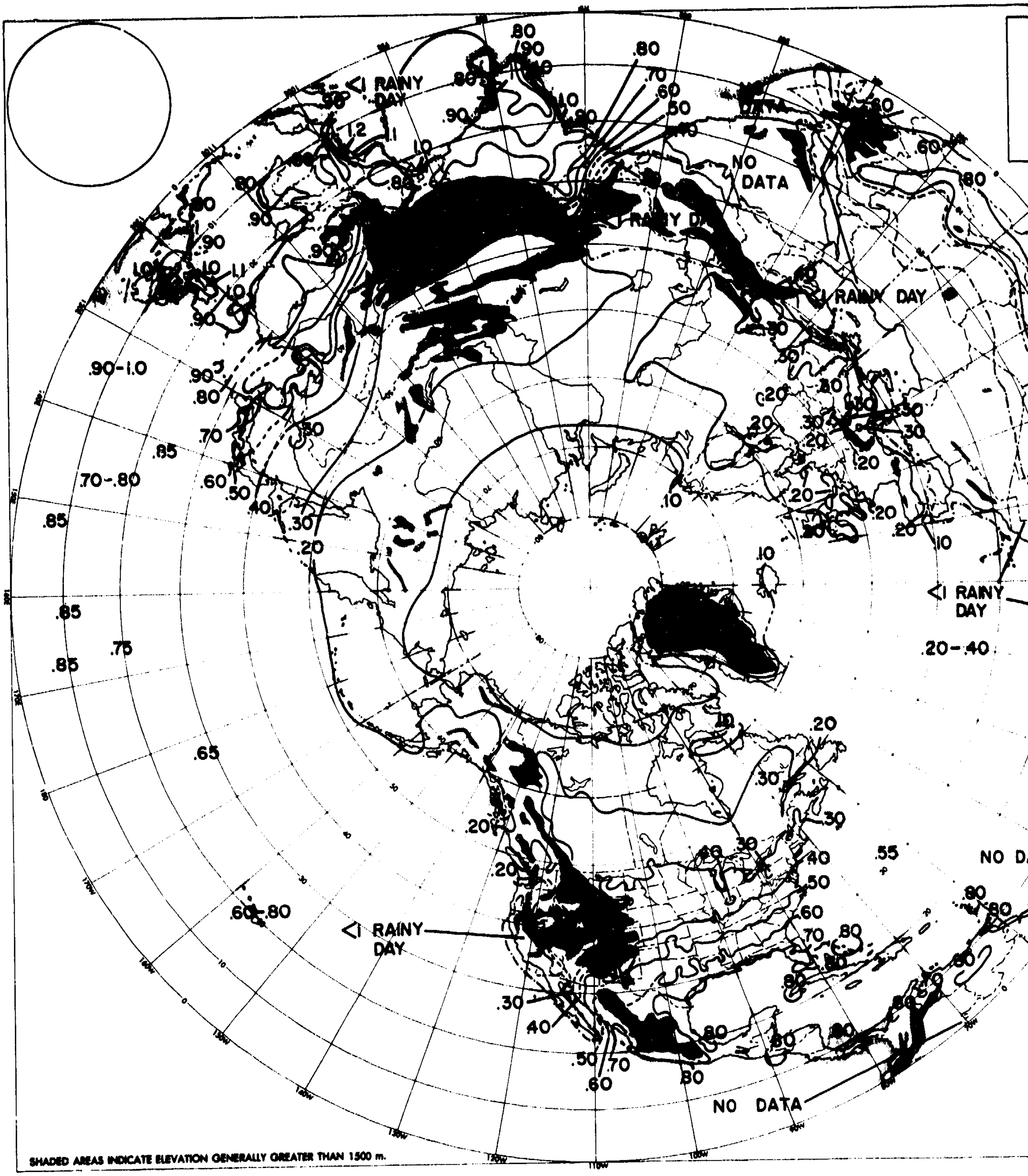

Figure 14. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 0.10 Percent of the Time in July

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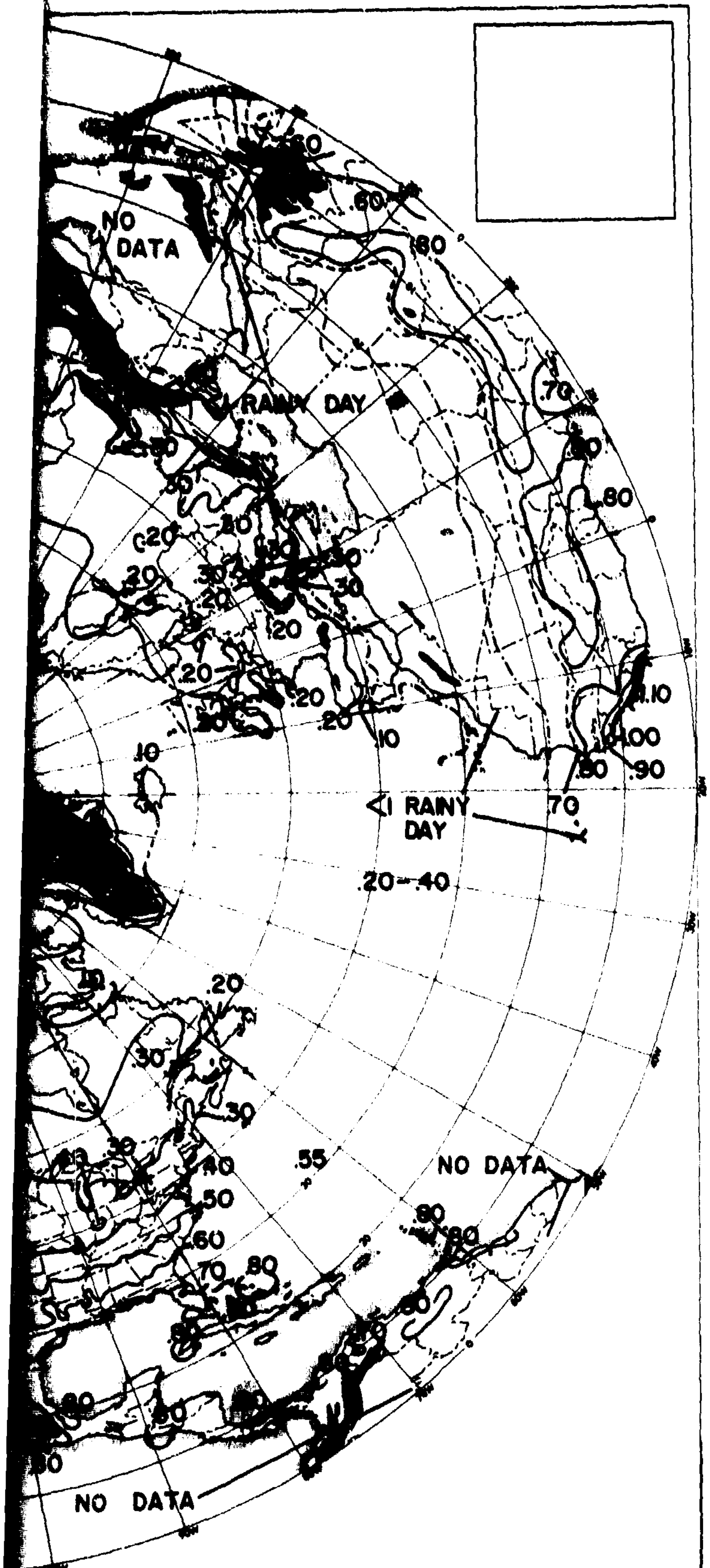
1 2


NO DATA
<1 RAINY DAY
.60
.70
.80
.10
.00
.90
.20
.30
.10
<1 RAINY DAY
.70
.20-.40
.20
.30
.40
.50
.60
.55
NO DATA
.80
NO DATA

rcent

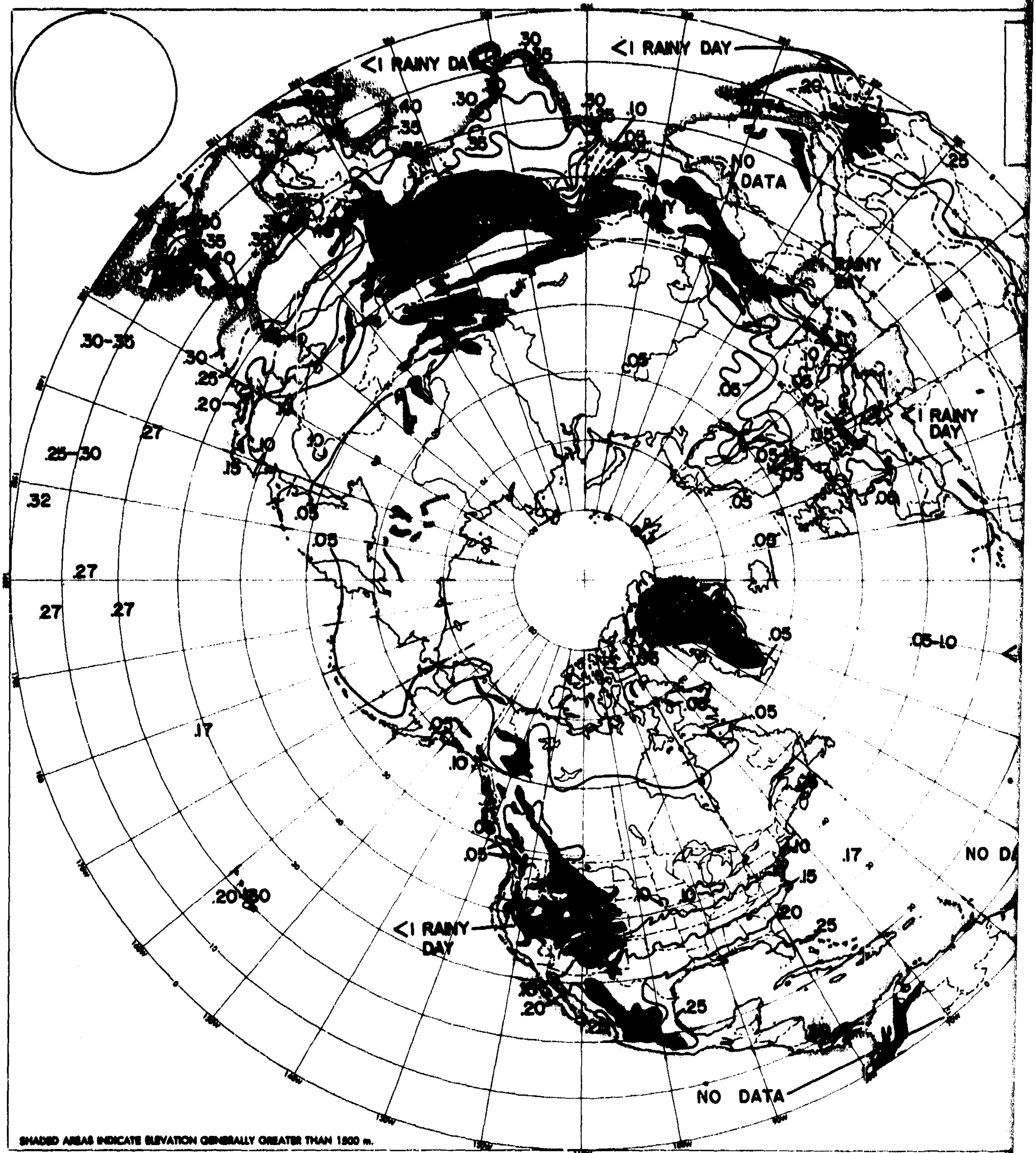
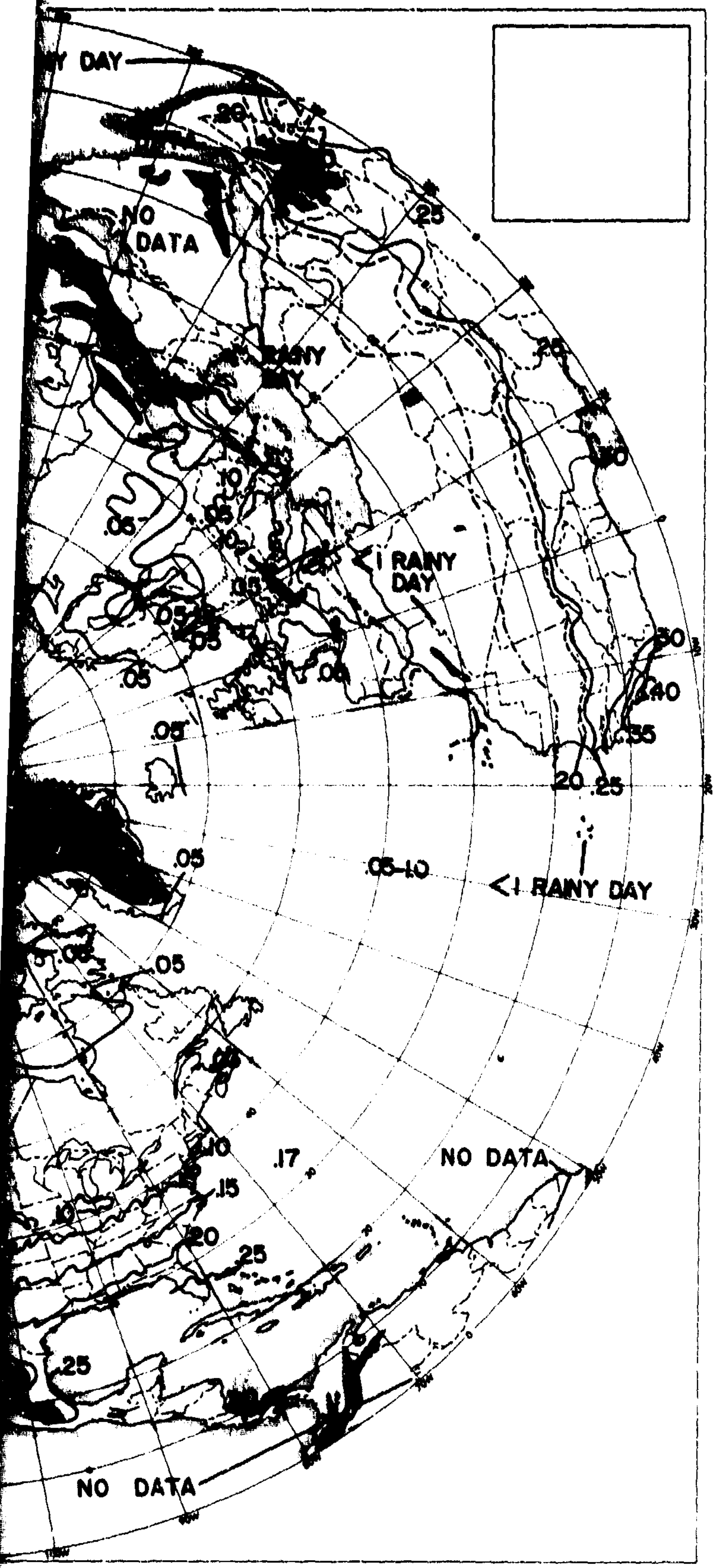


Figure 15. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 0.50 Percent of the Time in July

2


DAY
.20
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DATA
.25
.25
RAINY
DAY
.30
.10
.05
.05
.10
<1 RAINY
DAY
.05
.05
.05
.05
.30
.40
.55
.20
.25
.05
.05-.10
<1 RAINY DAY
.05
.05
.05
.10
.17
NO DATA
.15
.10
.20
.25
.25
NO DATA

Percent

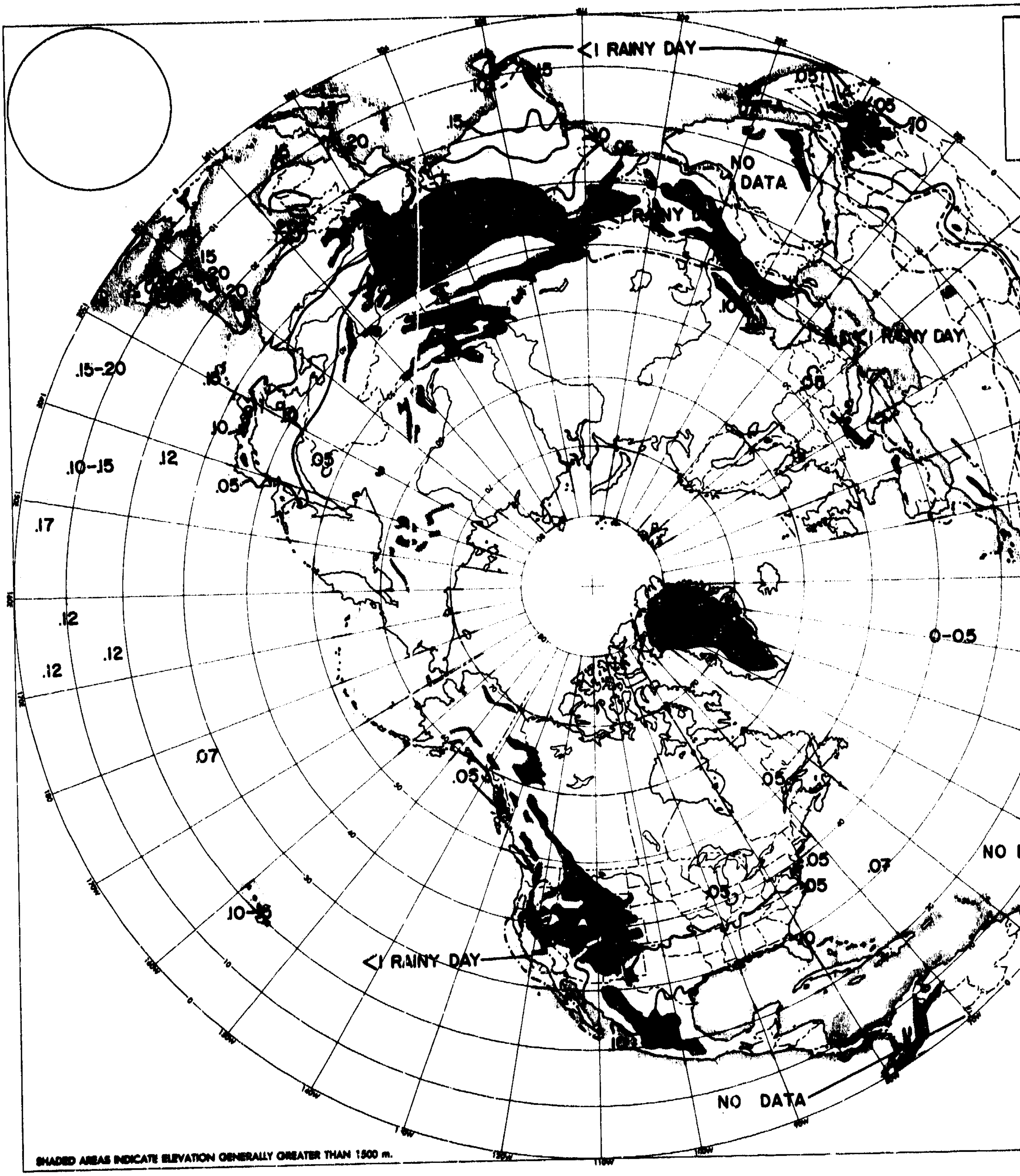
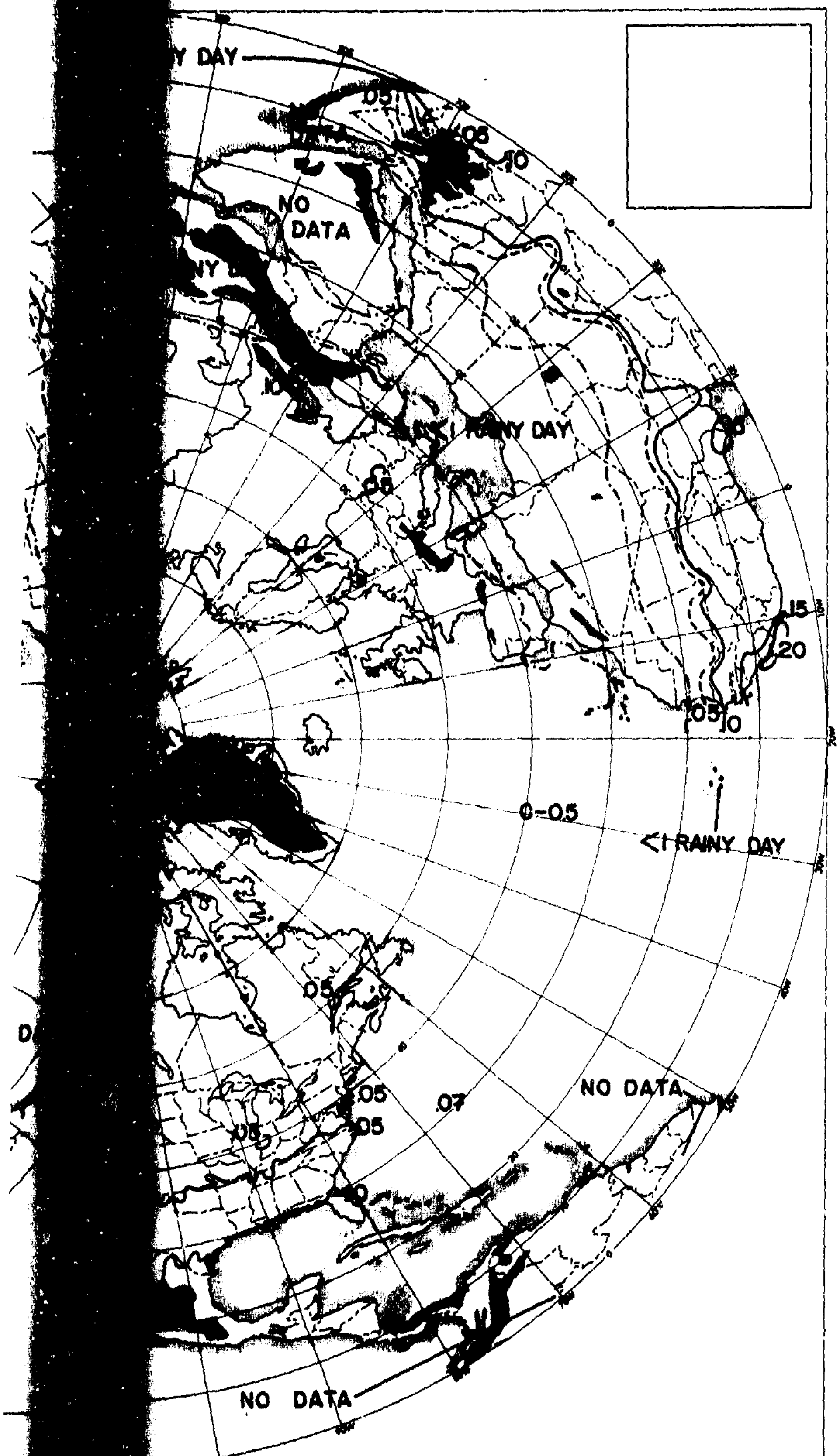


Figure 16. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 1.0 Percent of the Time in July

2



Percent of

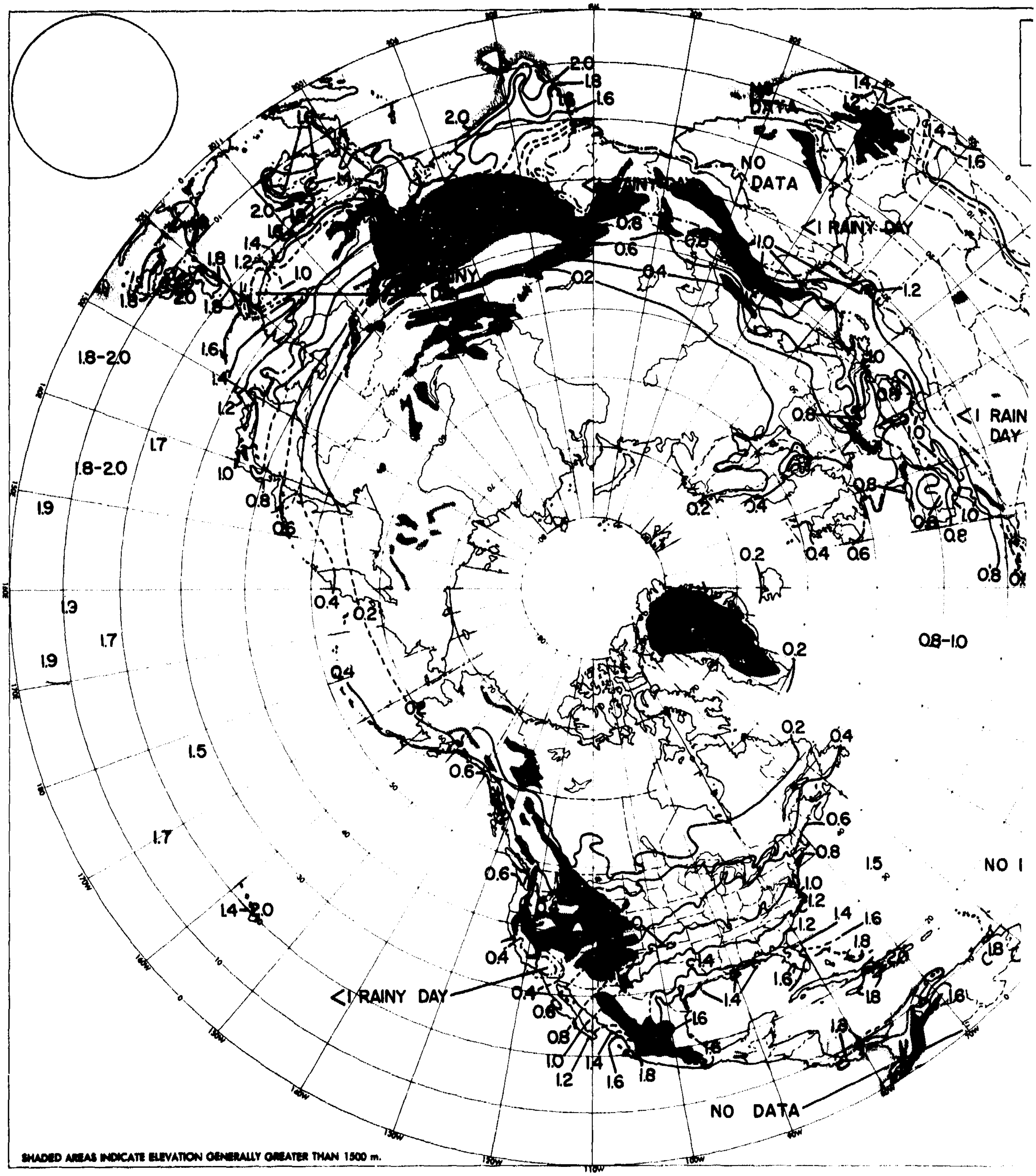
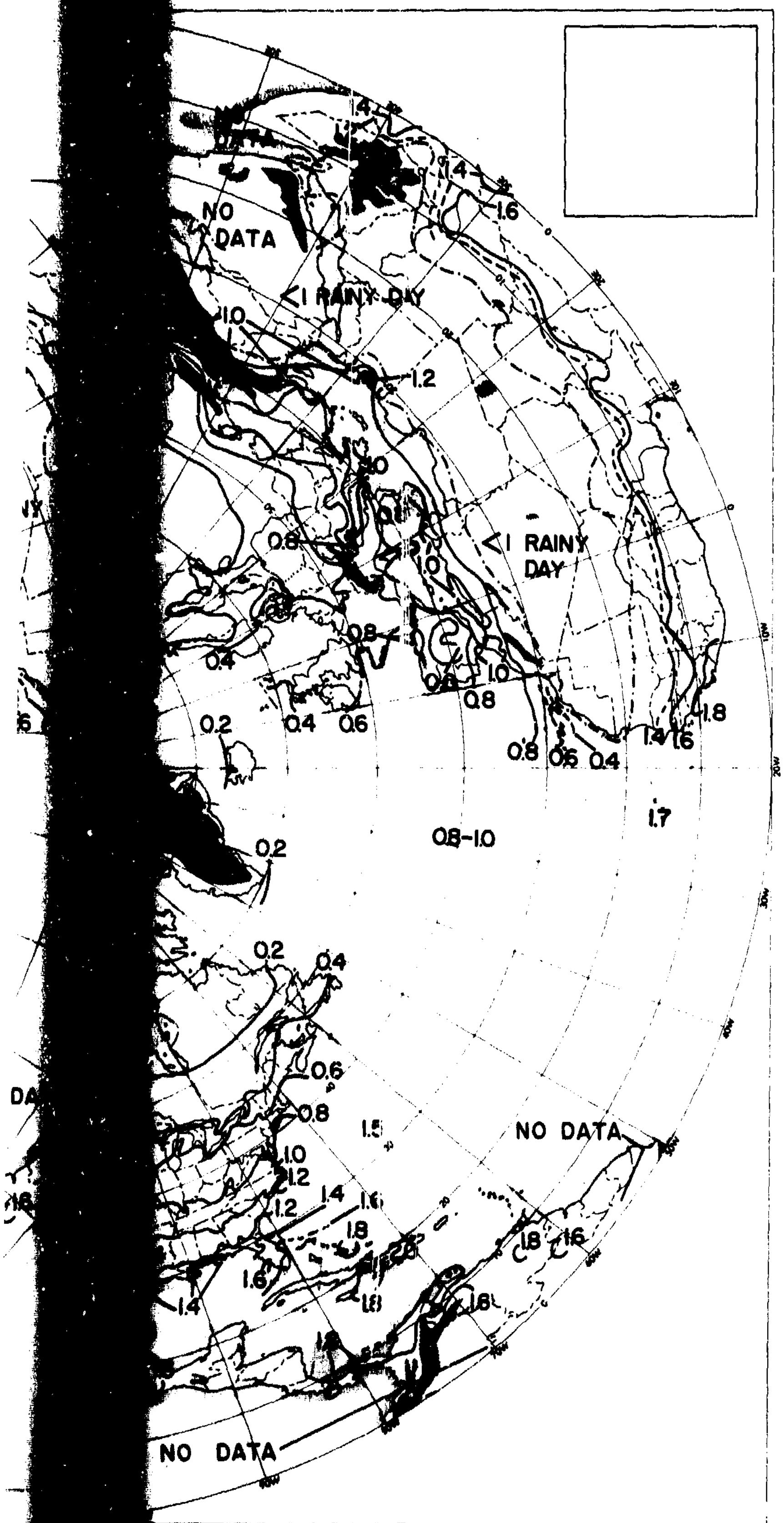


Figure 17. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 0.01 Percent of the Time in October

2



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1.2
1.4
1.6
1.0
0.8
<1 RAINY
DAY
1.0
0.8
0.4
1.0
0.8
0.2
0.4
0.6
0.8
0.6
0.4
1.4
1.6
1.8
1.7
0.8-1.0
0.2
0.2
0.4
0.6
0.8
1.5
NO DATA
1.0
1.2
1.2
1.4
1.6
1.8
1.8
1.6
1.6
1.8
1.4
1.8
NO DATA

ent of

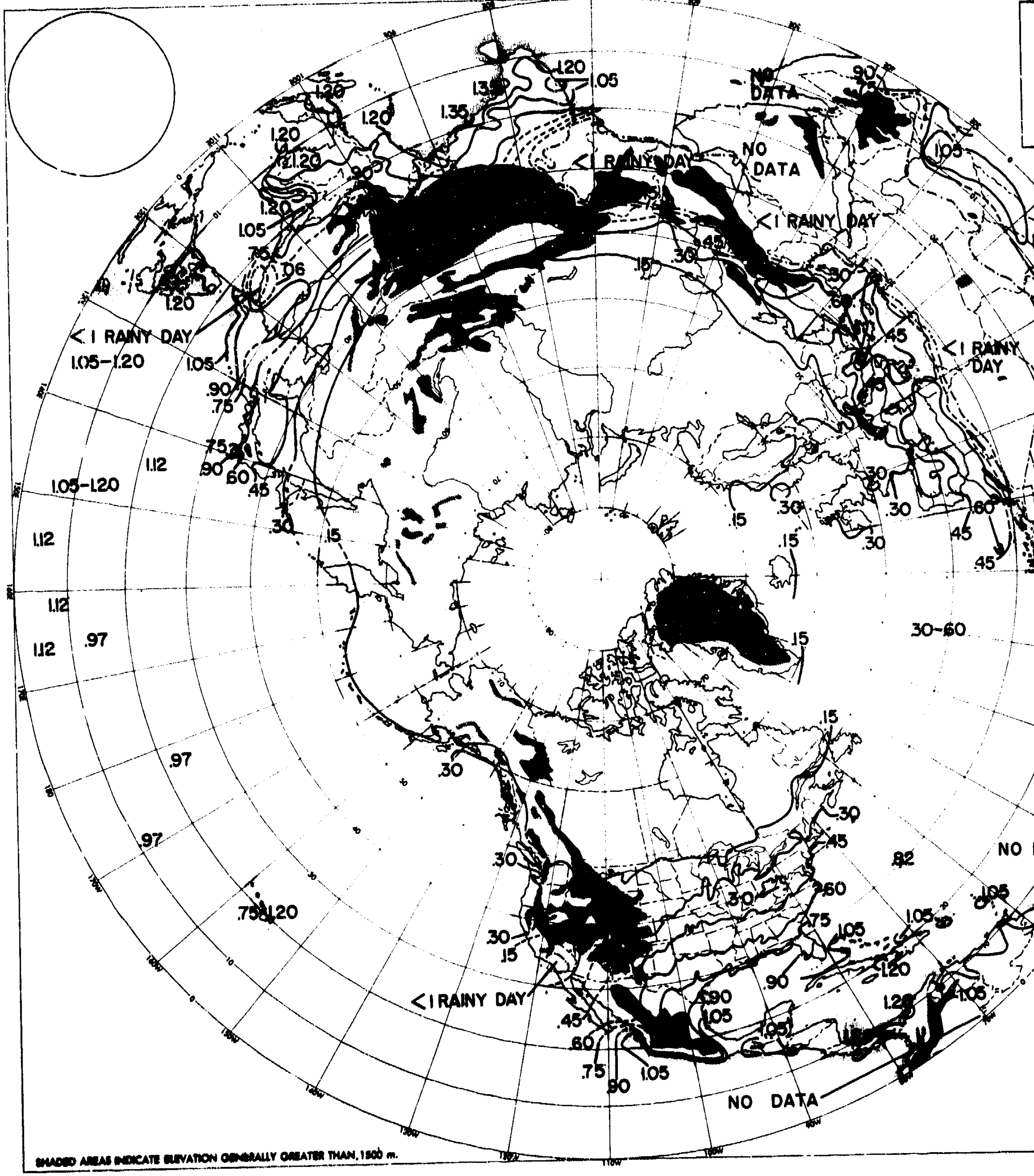
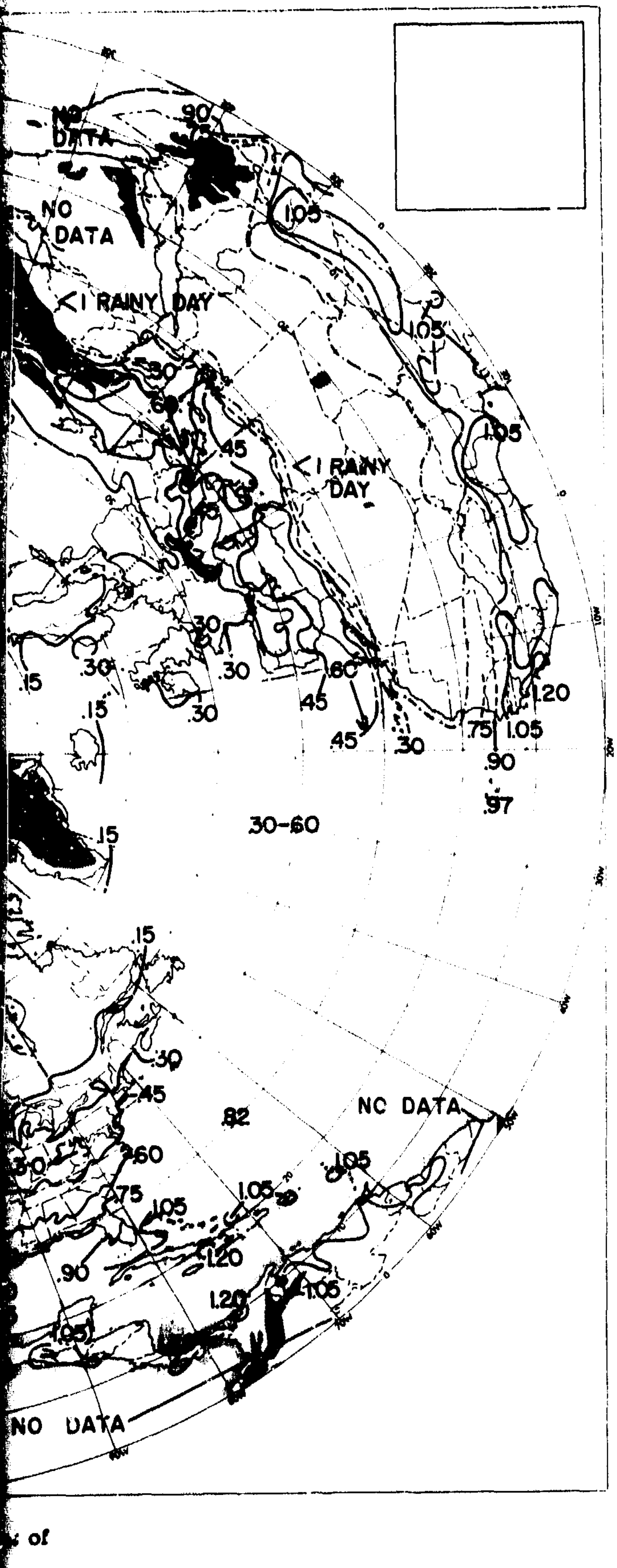


Figure 18. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 0.05 Percent of the Time in October

1

2



of

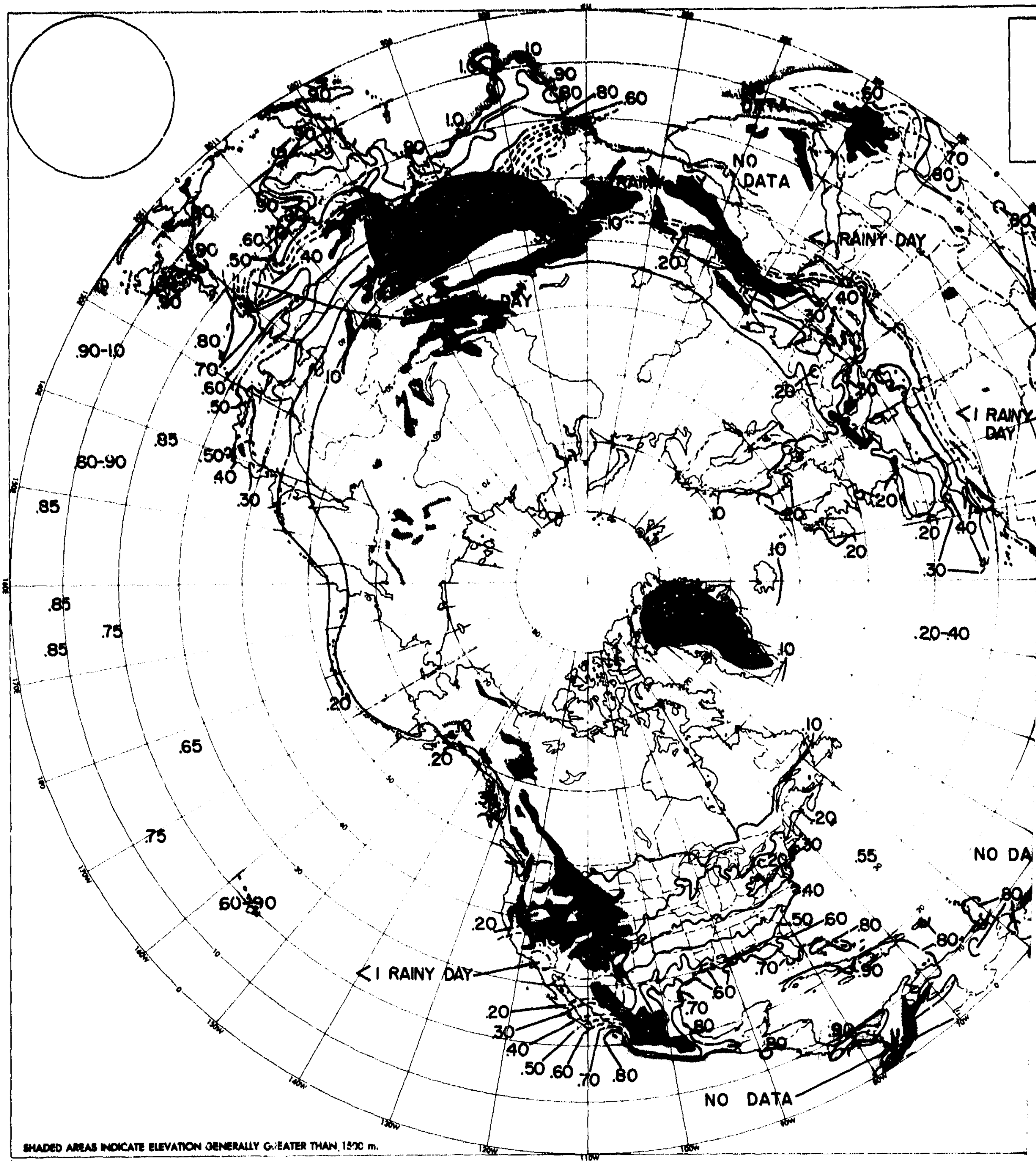
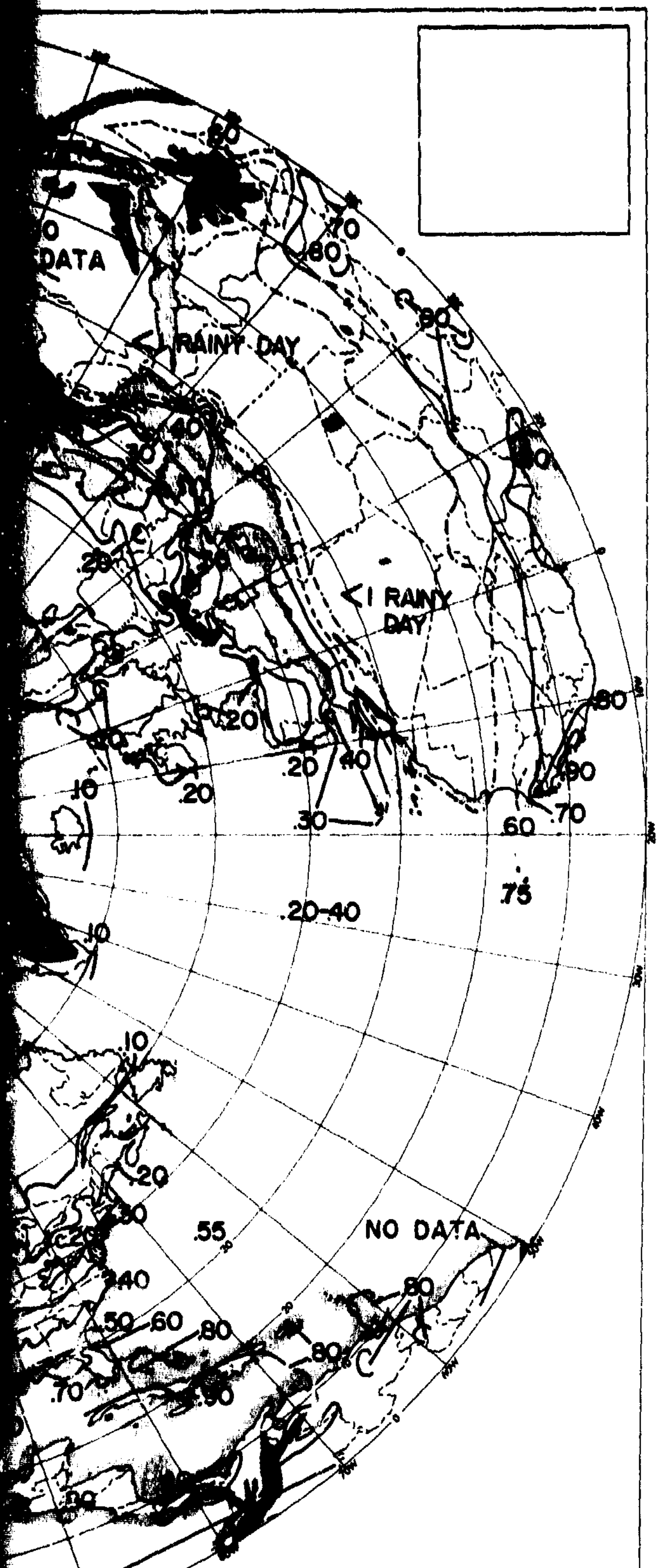


Figure 19. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 0.10 Percent of the Time in October

2



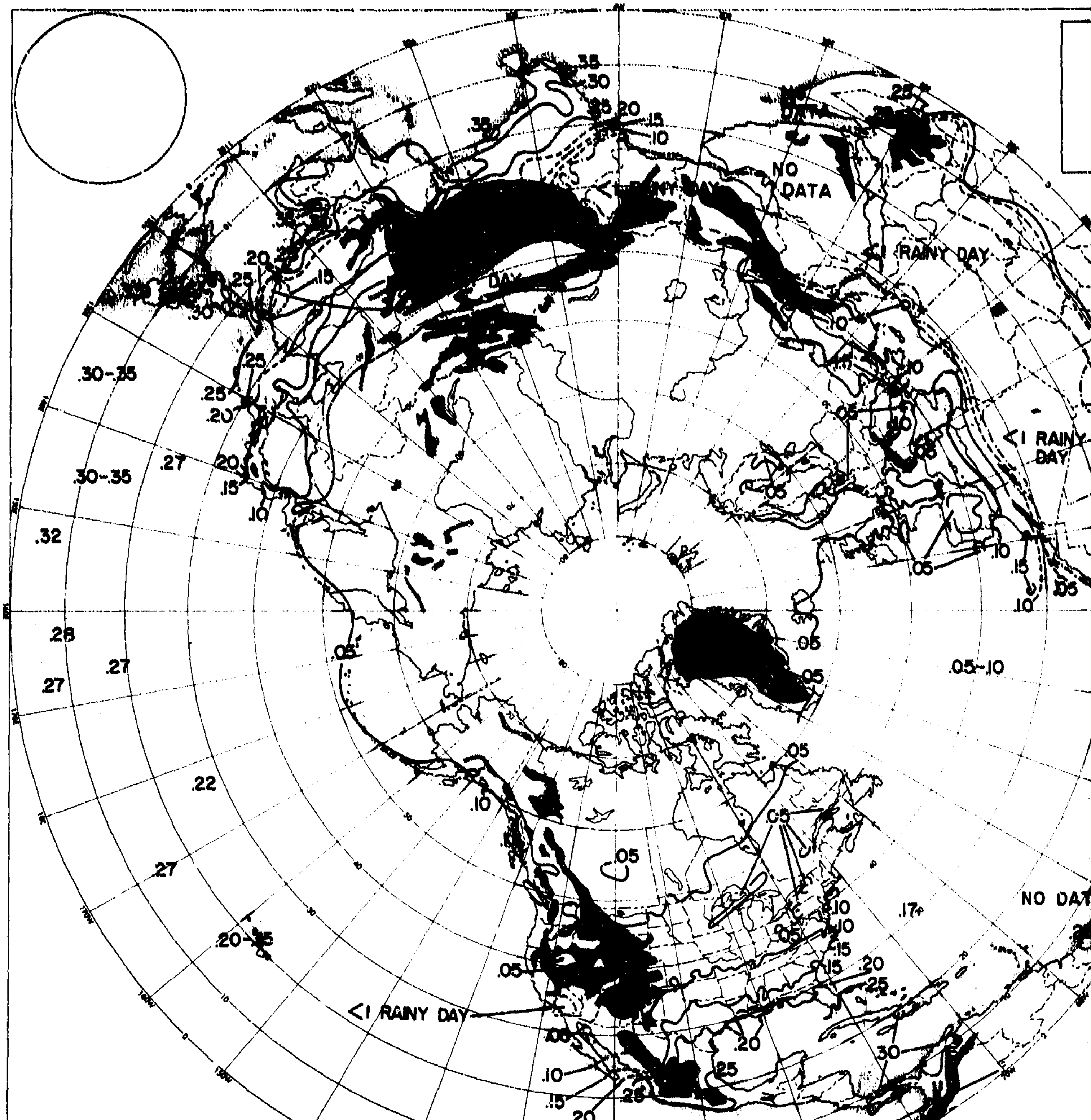
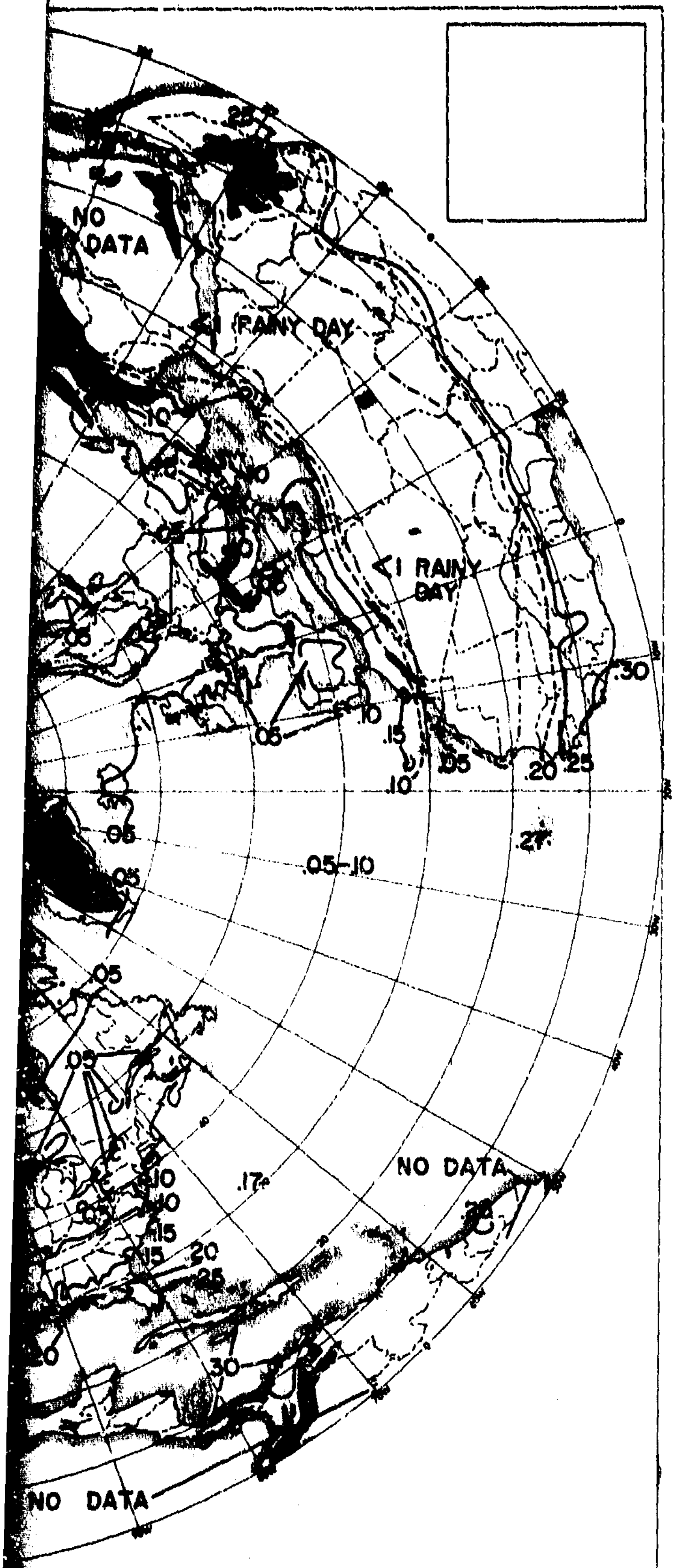


Figure 20. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 0.50 Percent of the Time in October

2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RAINY DAY
<1 RAINY DAY
.25
.10
.05
.15
.20
.30
.27
.05-.10
.17
NO DATA
NO DATA

of

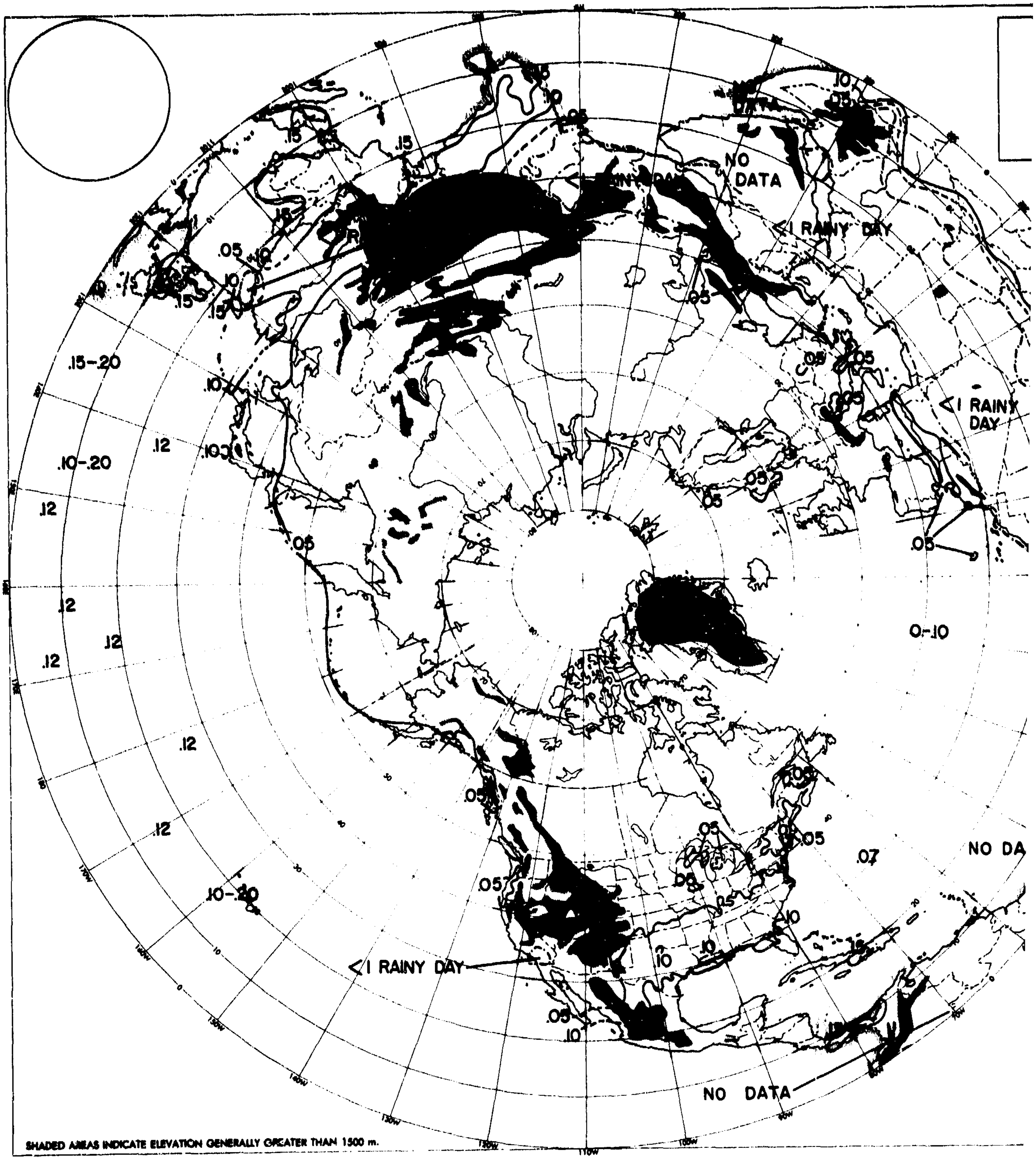

Figure 21. One-Min Rainfall Rate (mm/min) Equalled or Exceeded 1.0 Percent of the Time in October

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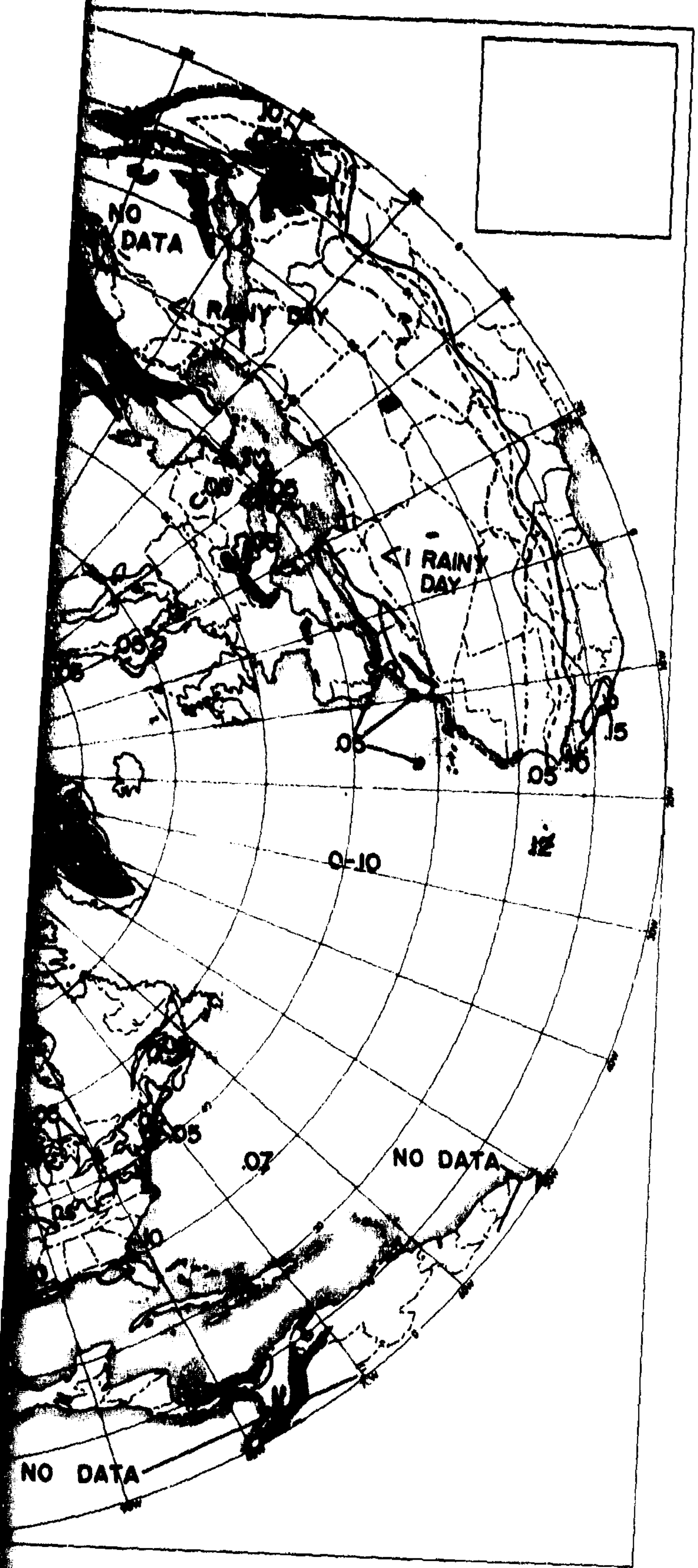
2



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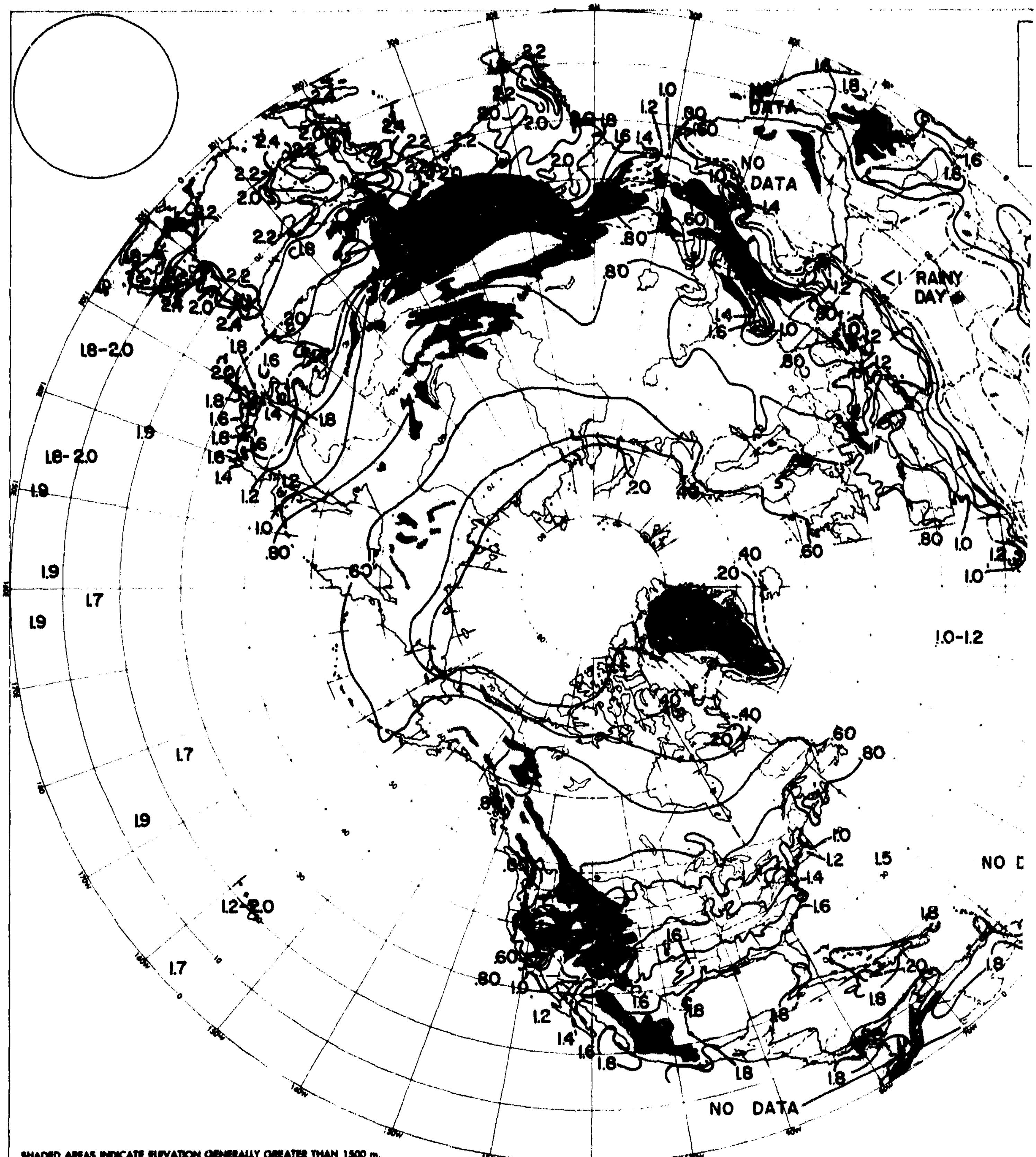
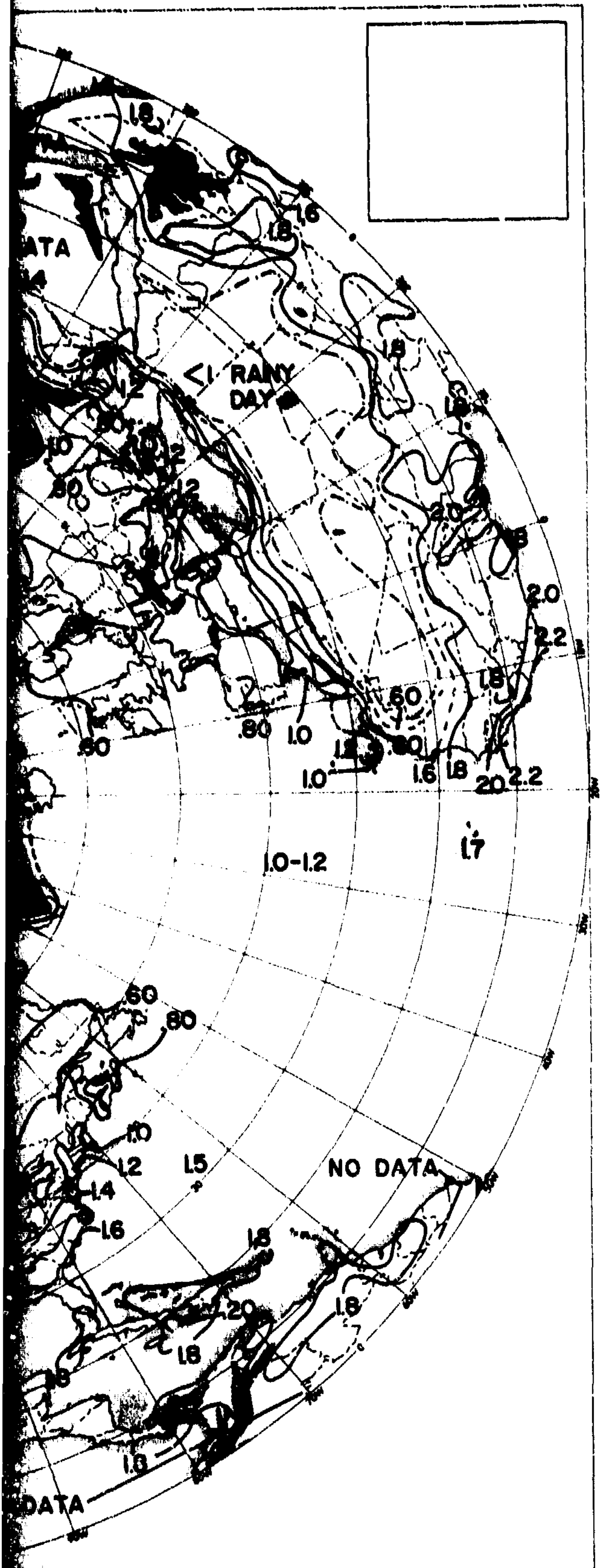


Figure 22. Highest 1-Min Rainfall Rates (mm/min) Equalled or Exceeded 0.01 Percent of the Time in Any Month

2



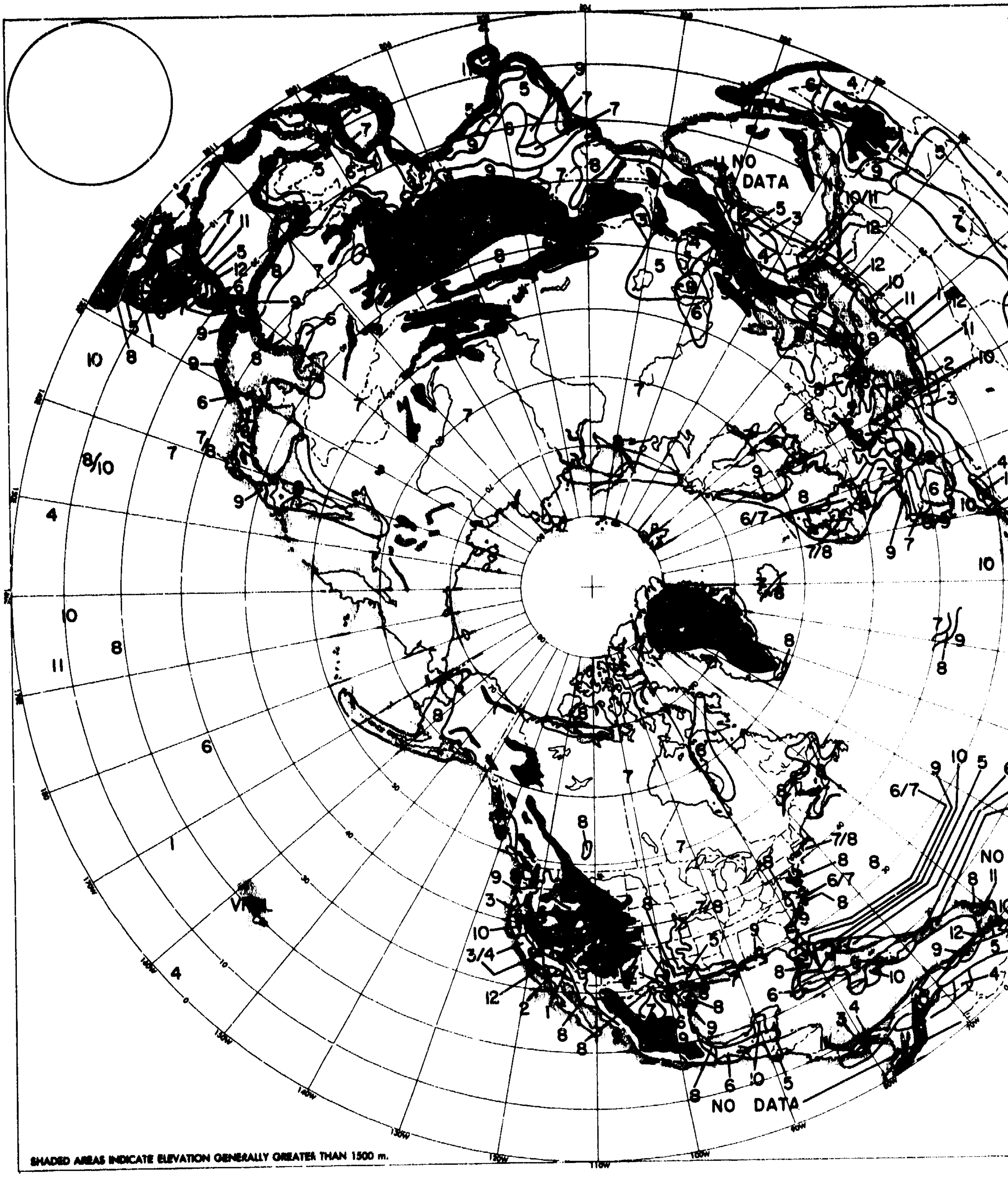
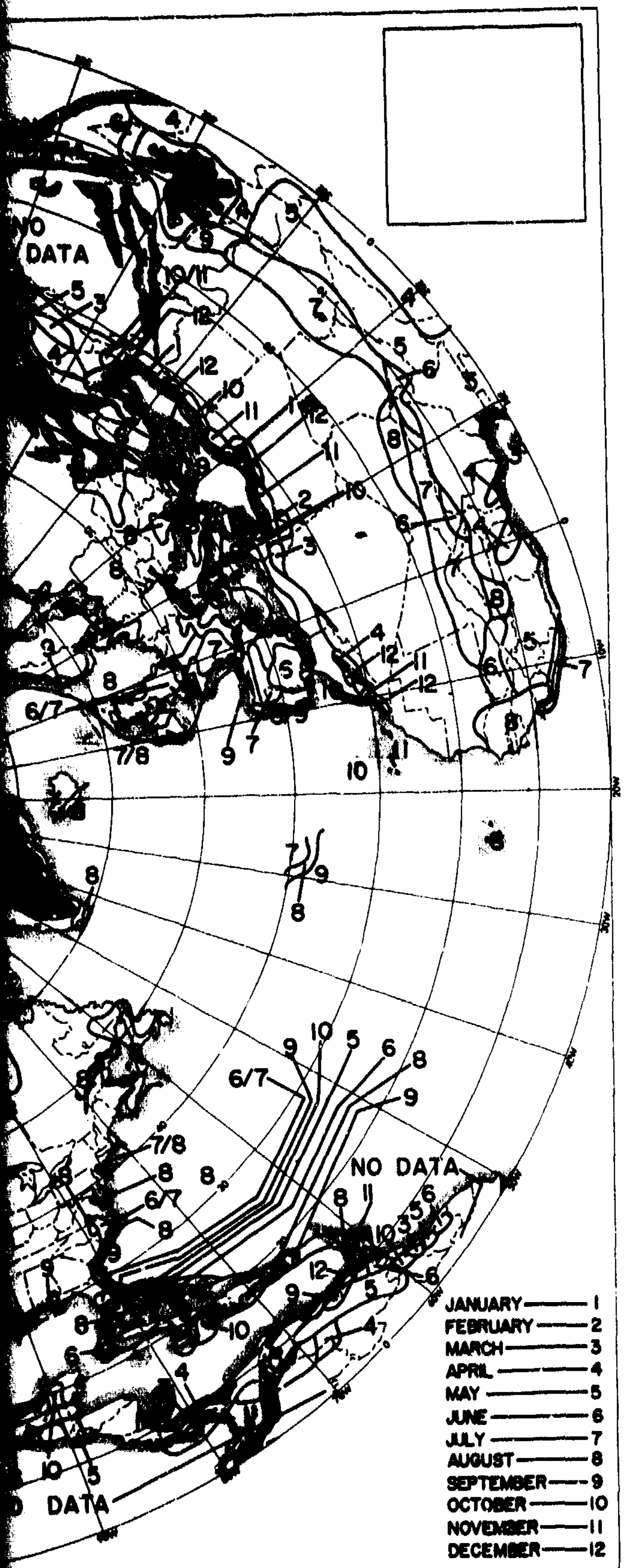


Figure 23. Month With the Highest 1-Min Rainfall Rates Equalled or Exceeded 0.01 Percent of the Time

1 2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NO DATA
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FEBRUARY — 2
MARCH — 3
APRIL — 4
MAY — 5
JUNE — 6
JULY — 7
AUGUST — 8
SEPTEMBER — 9
OCTOBER — 10
NOVEMBER — 11
DECEMBER — 12

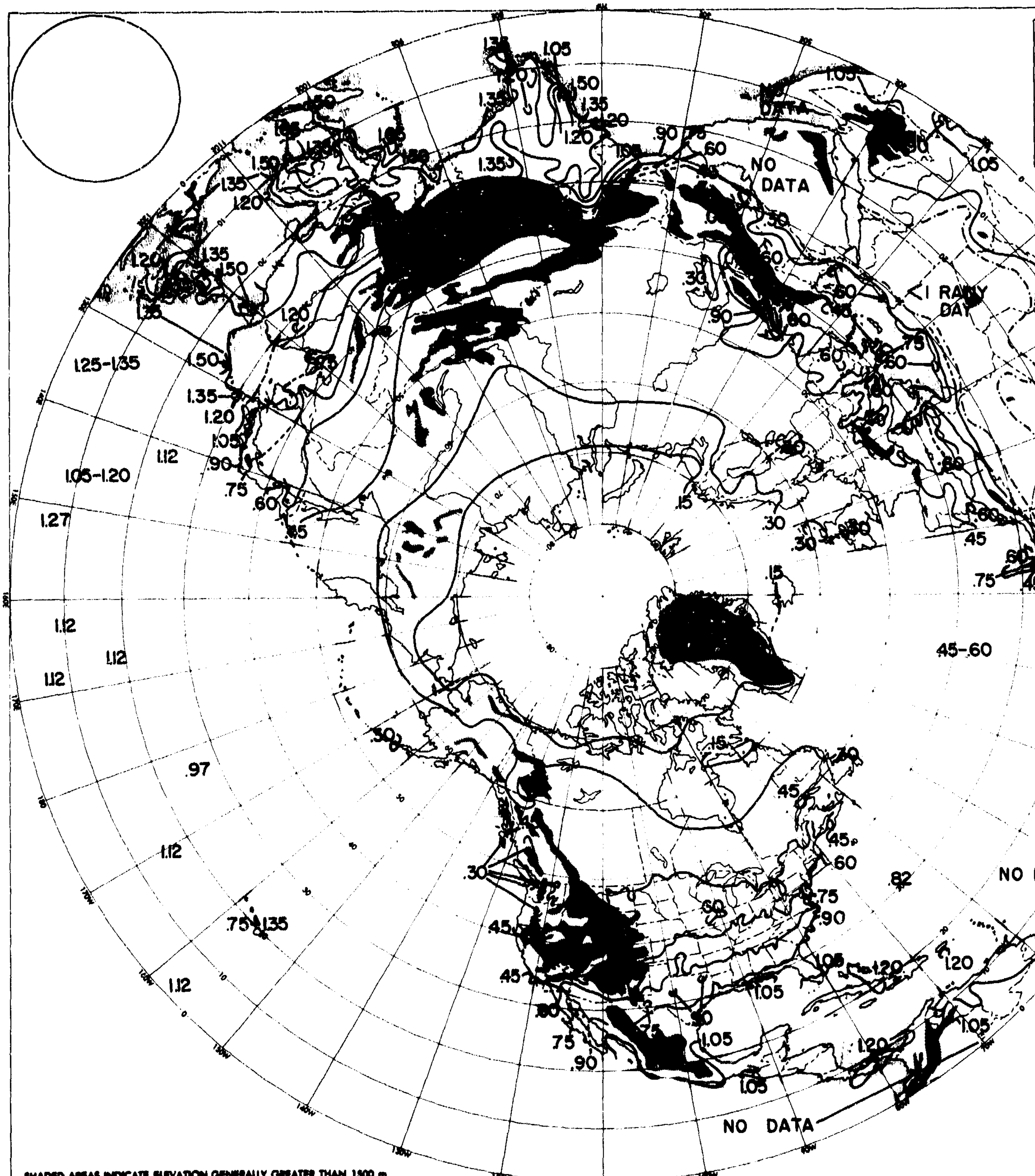
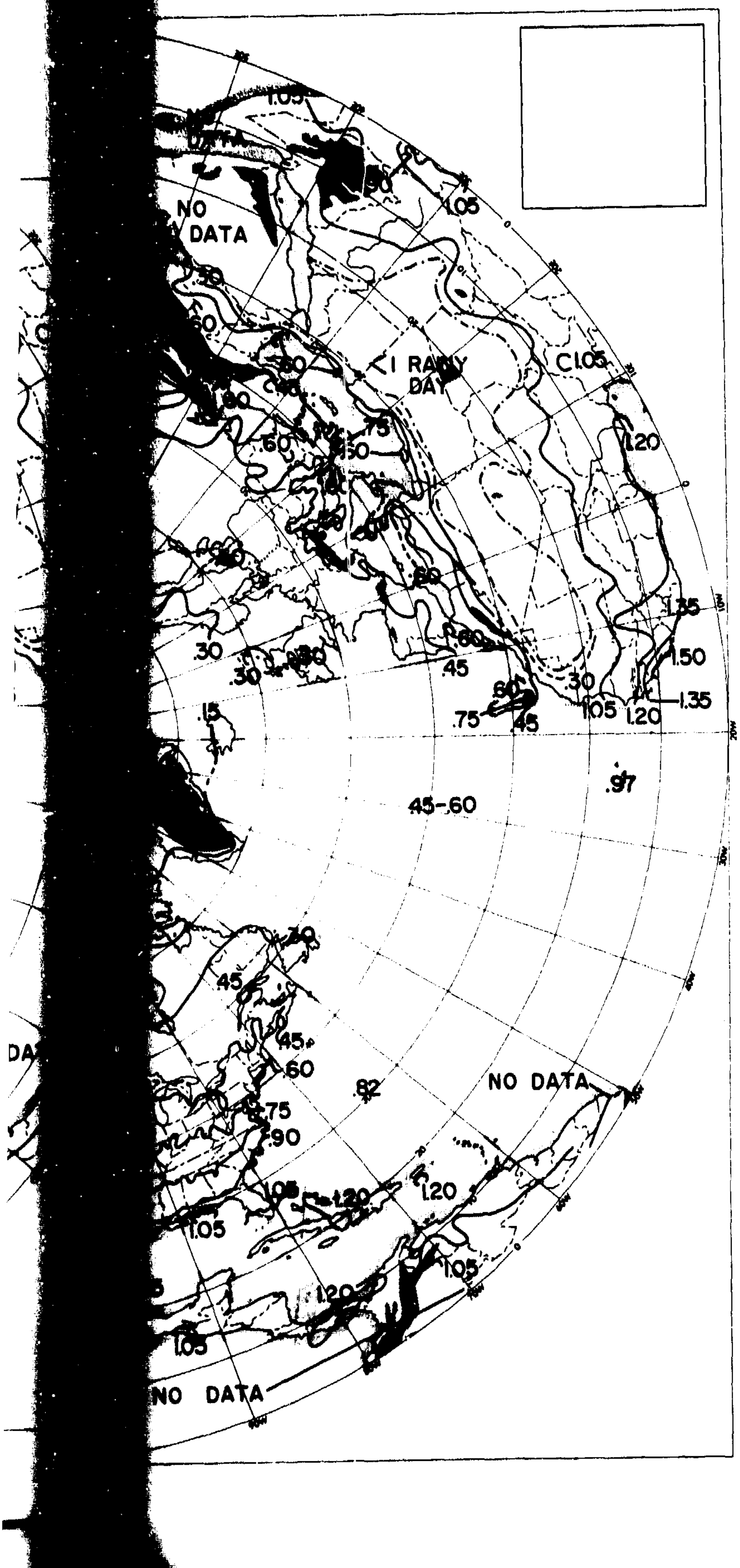


Figure 24. Highest 1-Min Rainfall Rates (mm/min) Equalled or Exceeded 0.05 Percent of the Time in Any Month

2



1.05
NO
DATA
.30
.60
.90
<1 RAINY DAY
C1.05
1.20
.75
.60
1.35
1.50
.30
.45
.75
1.05
1.20
1.35
.15
.97
45-.60
.45
.82
NO DATA
.75
.90
1.05
1.20
NO DATA

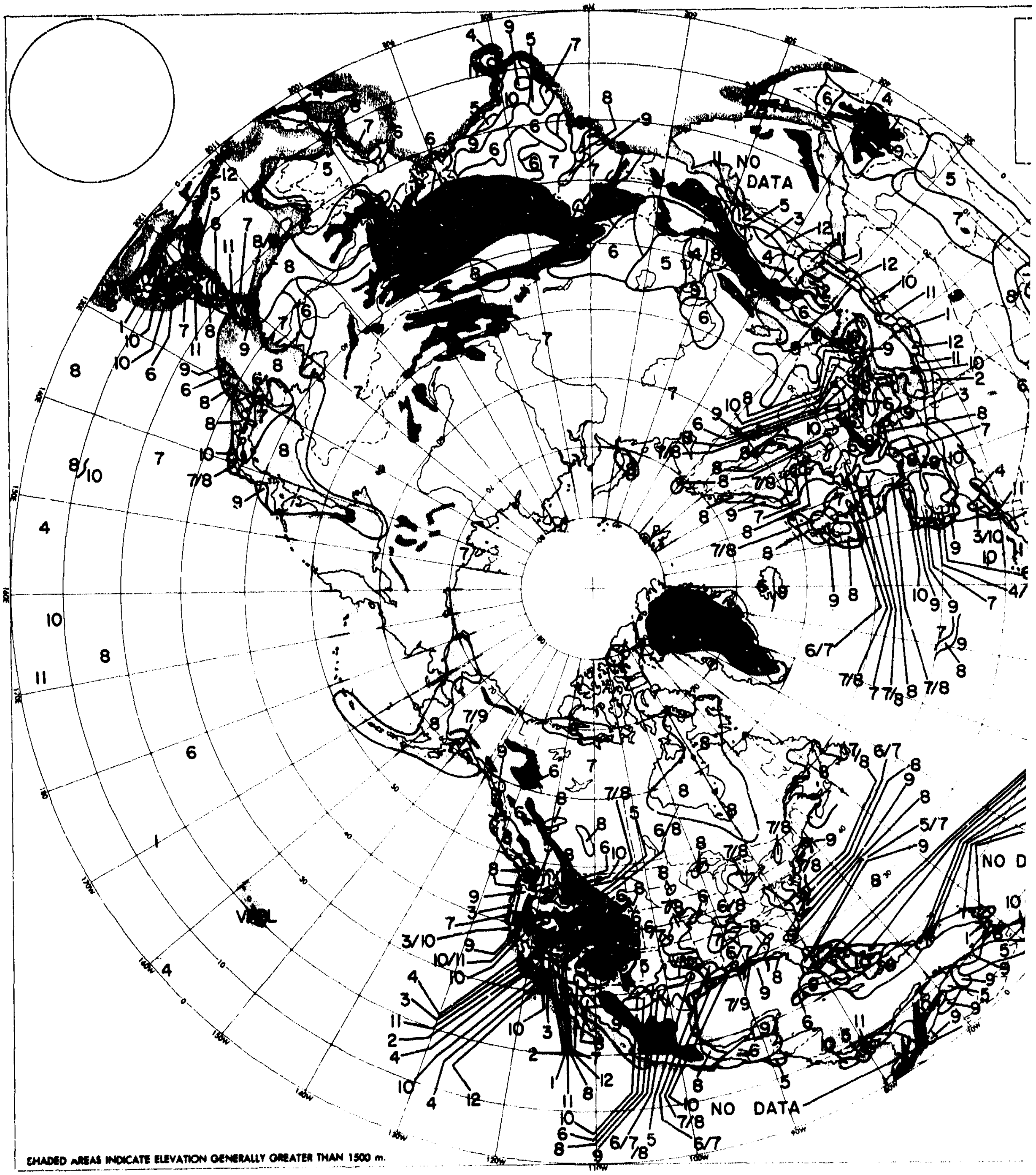
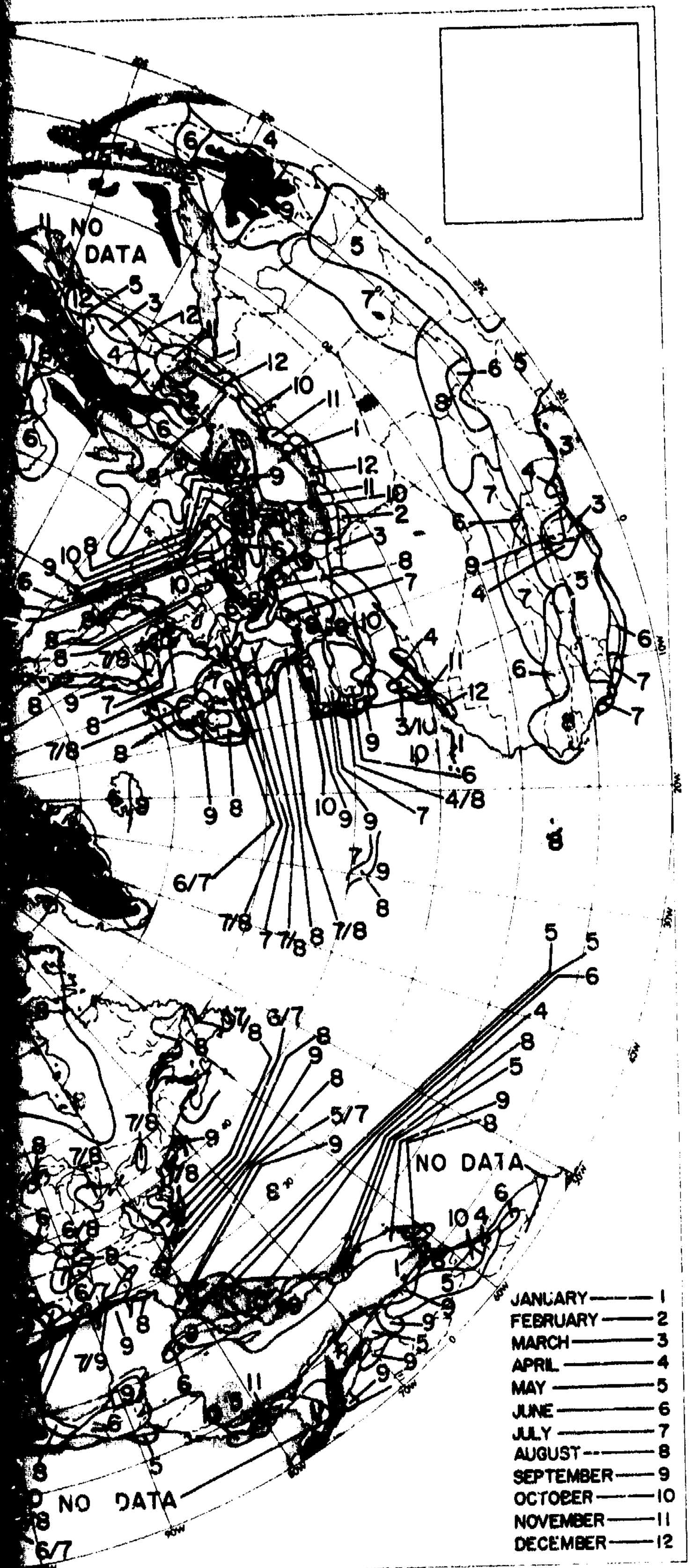


Figure 25. Month With the Highest 1-Min Rainfall Rates Equalled or Exceeded 0.05 Percent of the Time

2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NO DATA
NO DATA
JANUARY — 1
FEBRUARY — 2
MARCH — 3
APRIL — 4
MAY — 5
JUNE — 6
JULY — 7
AUGUST — 8
SEPTEMBER — 9
OCTOBER — 10
NOVEMBER — 11
DECEMBER — 12

ed

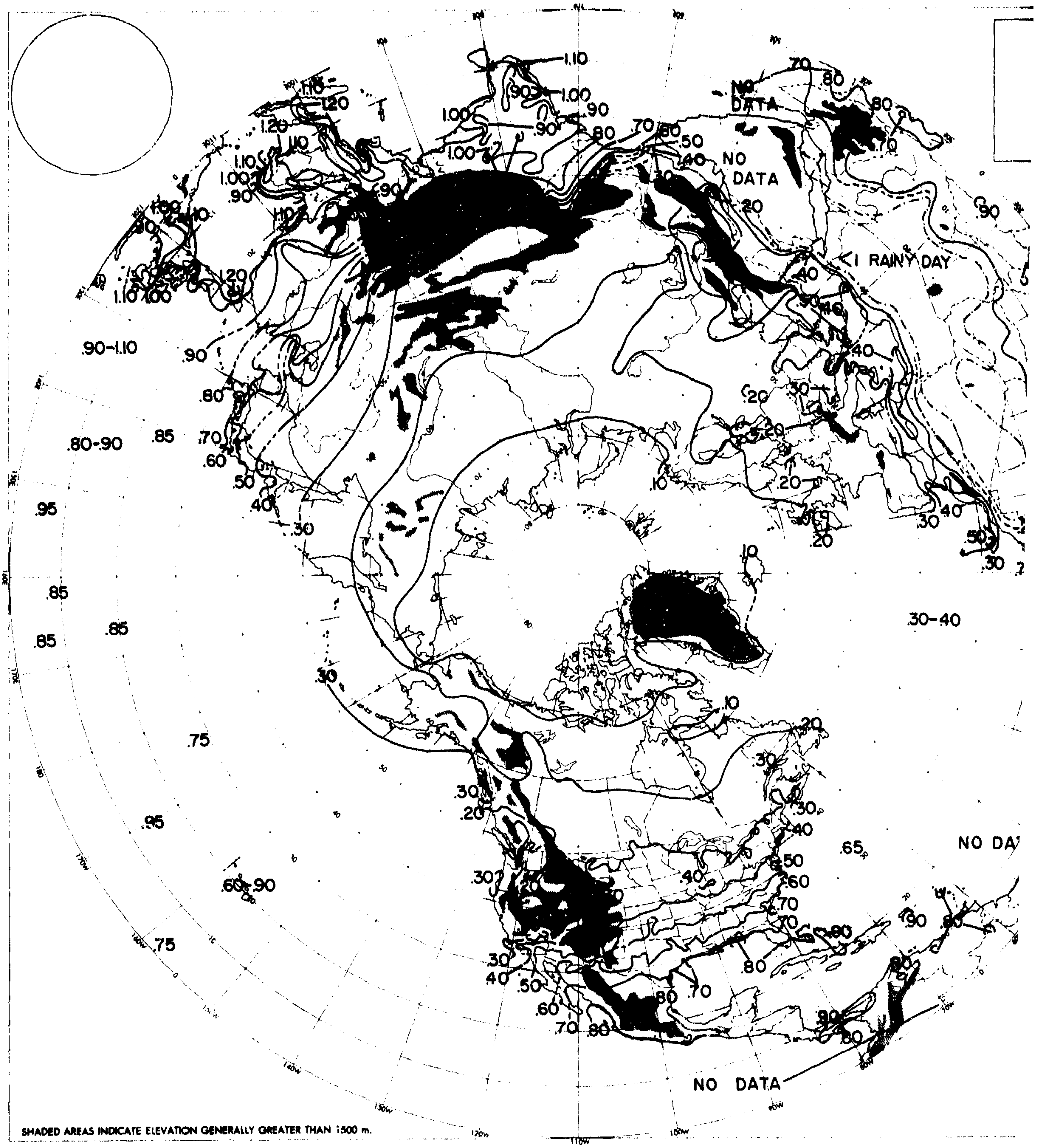
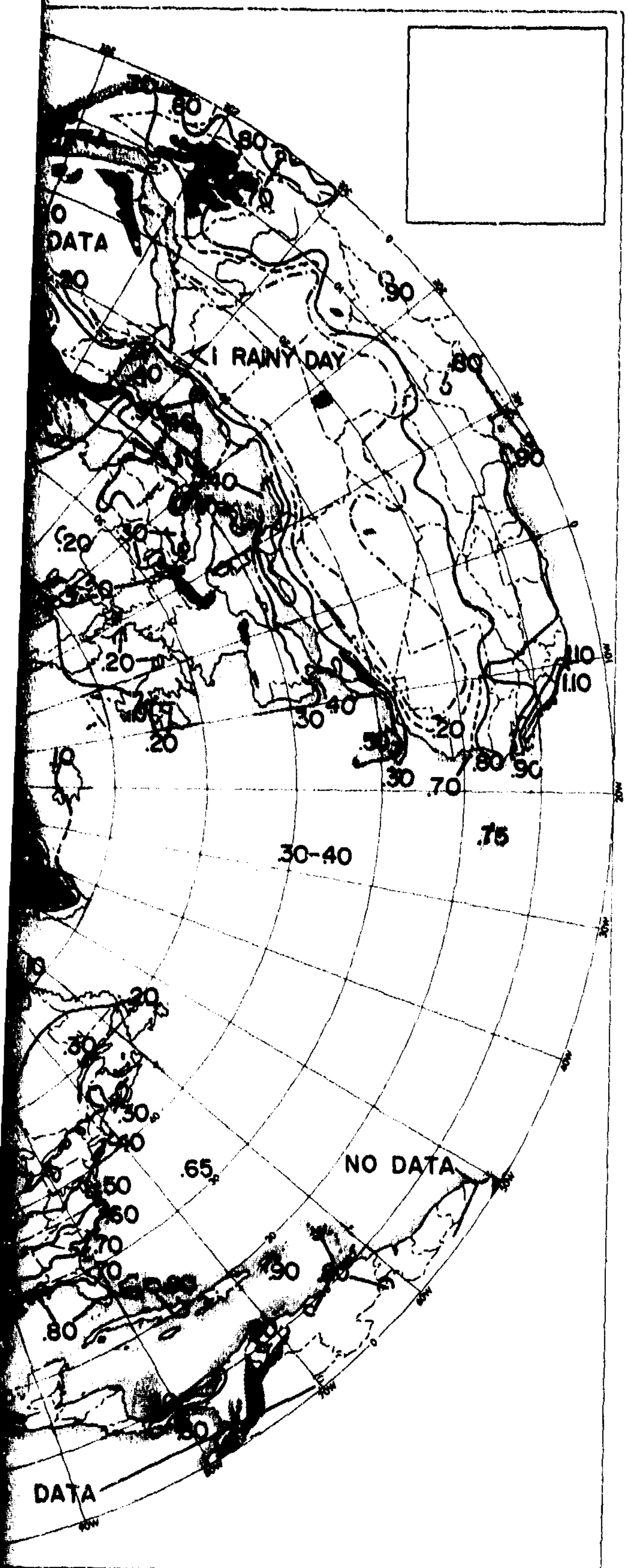


Figure 26. Highest 1-Min Rainfall Rates (mm/min) Equalled or Exceeded 0.10 Percent of the Time in Any Month

2



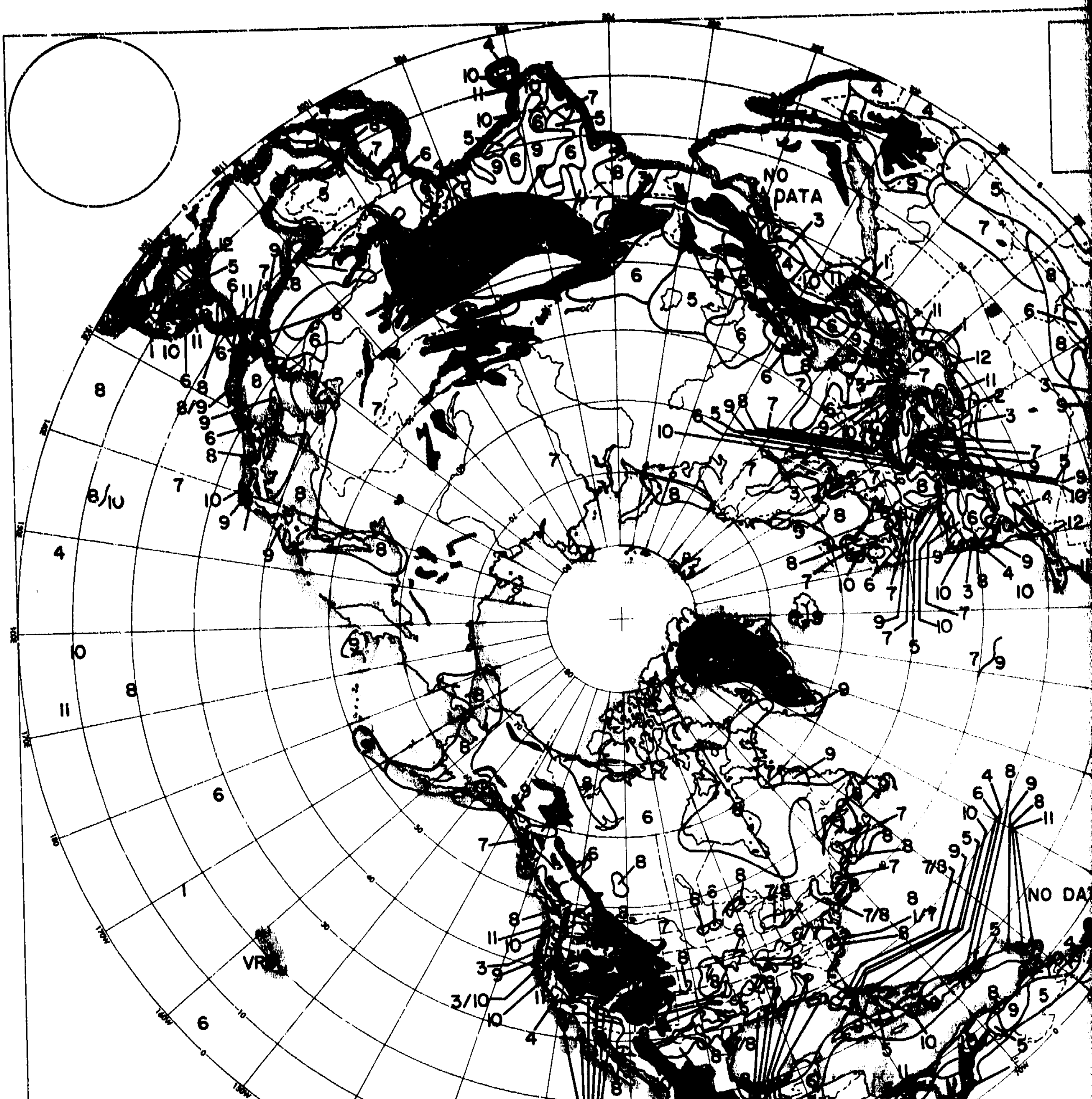
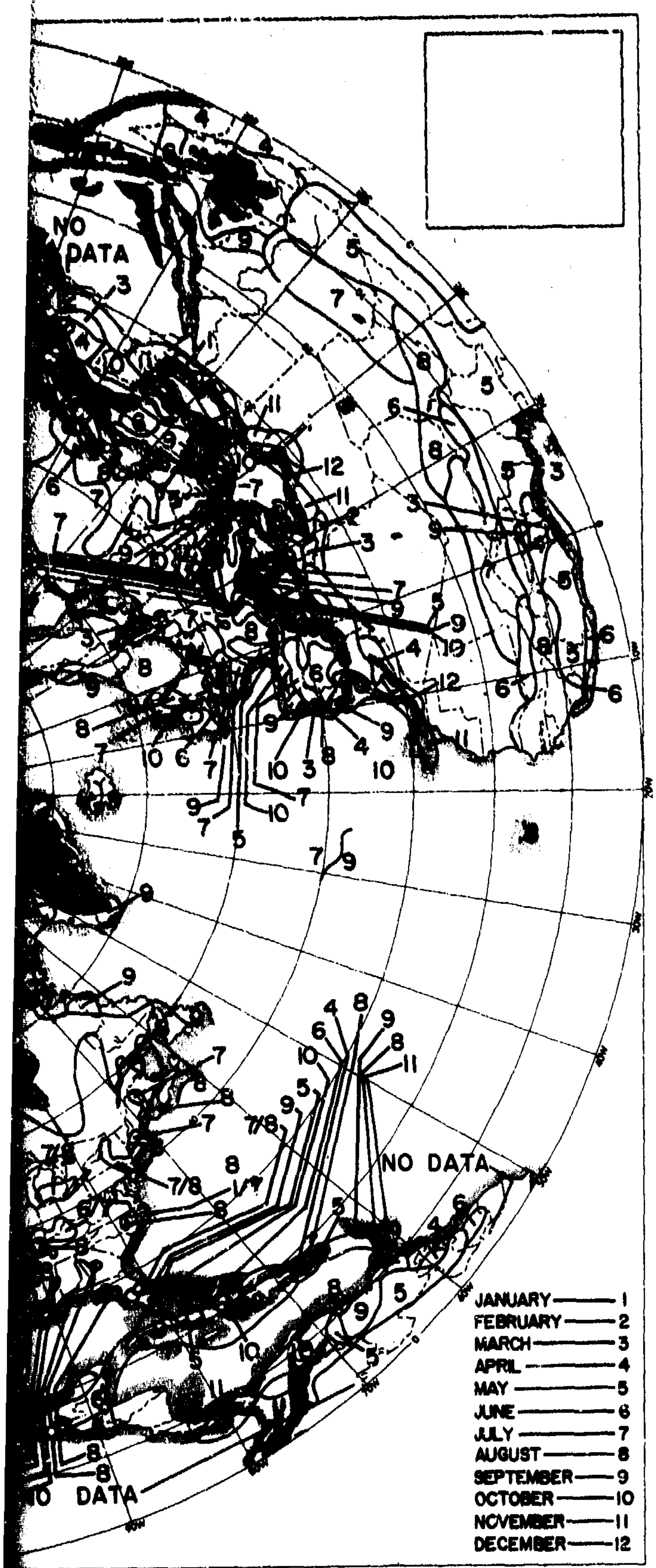


Figure 27. Month With the Highest 1-Min Rainfall Rates Equalled or Exceeded 0.10 Percent of the Time

2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NO DATA
NO DATA
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FEBRUARY — 2
MARCH — 3
APRIL — 4
MAY — 5
JUNE — 6
JULY — 7
AUGUST — 8
SEPTEMBER — 9
OCTOBER — 10
NOVEMBER — 11
DECEMBER — 12

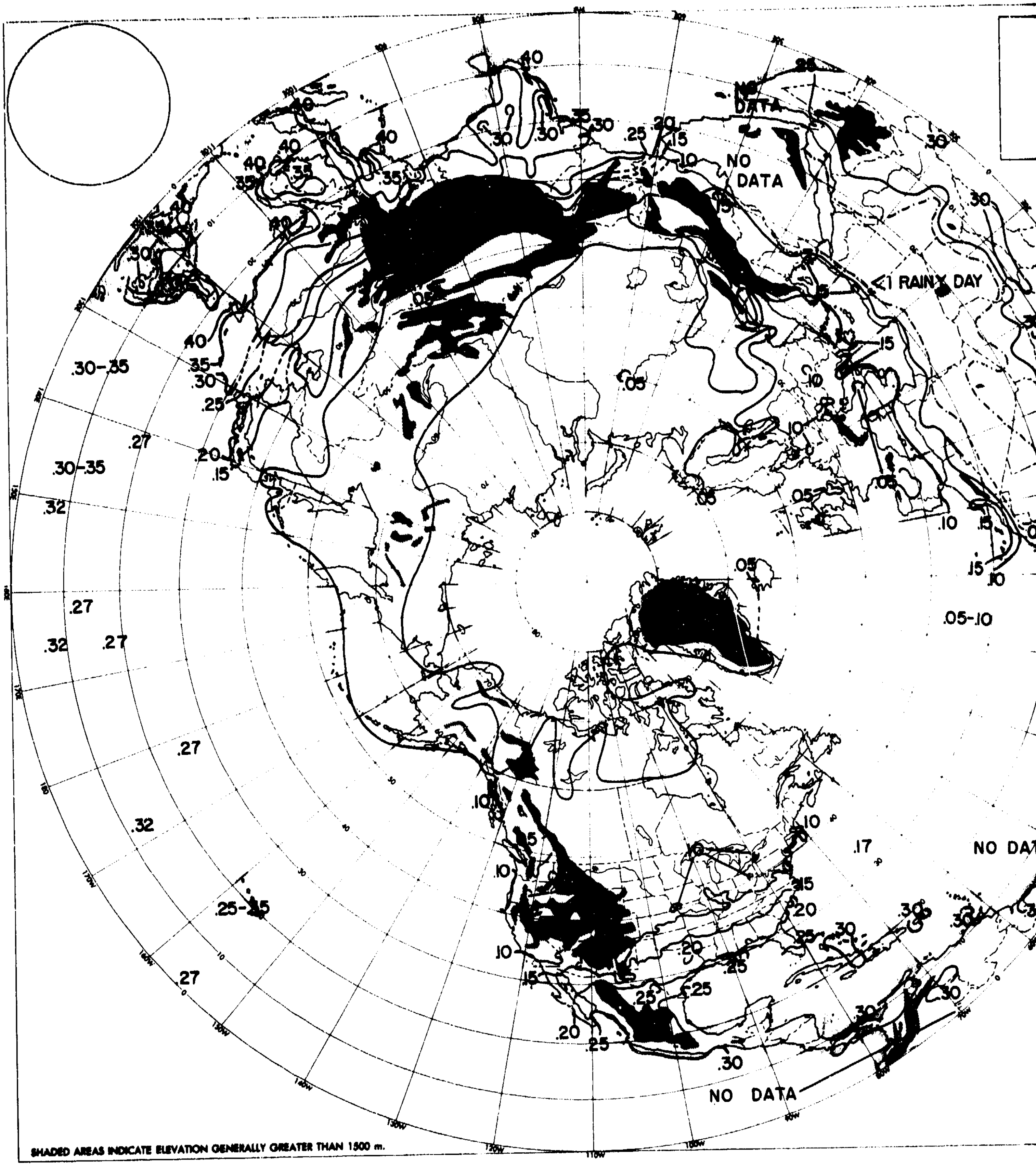
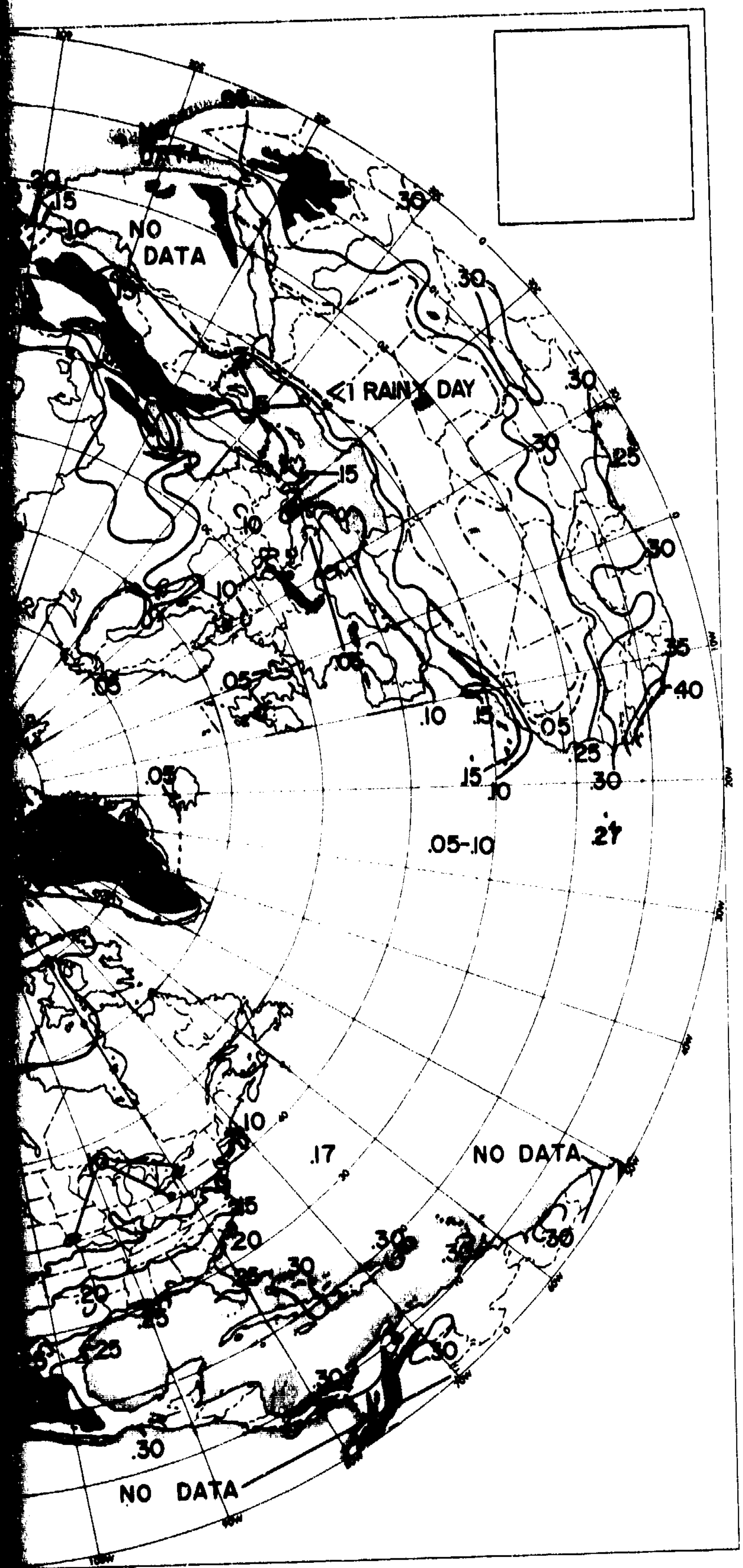


Figure 28. Highest 1-Min Rainfall Rates (mm/min) Equalled or Exceeded 0.50 Percent of the Time in Any Month

1 2



ed 0.50

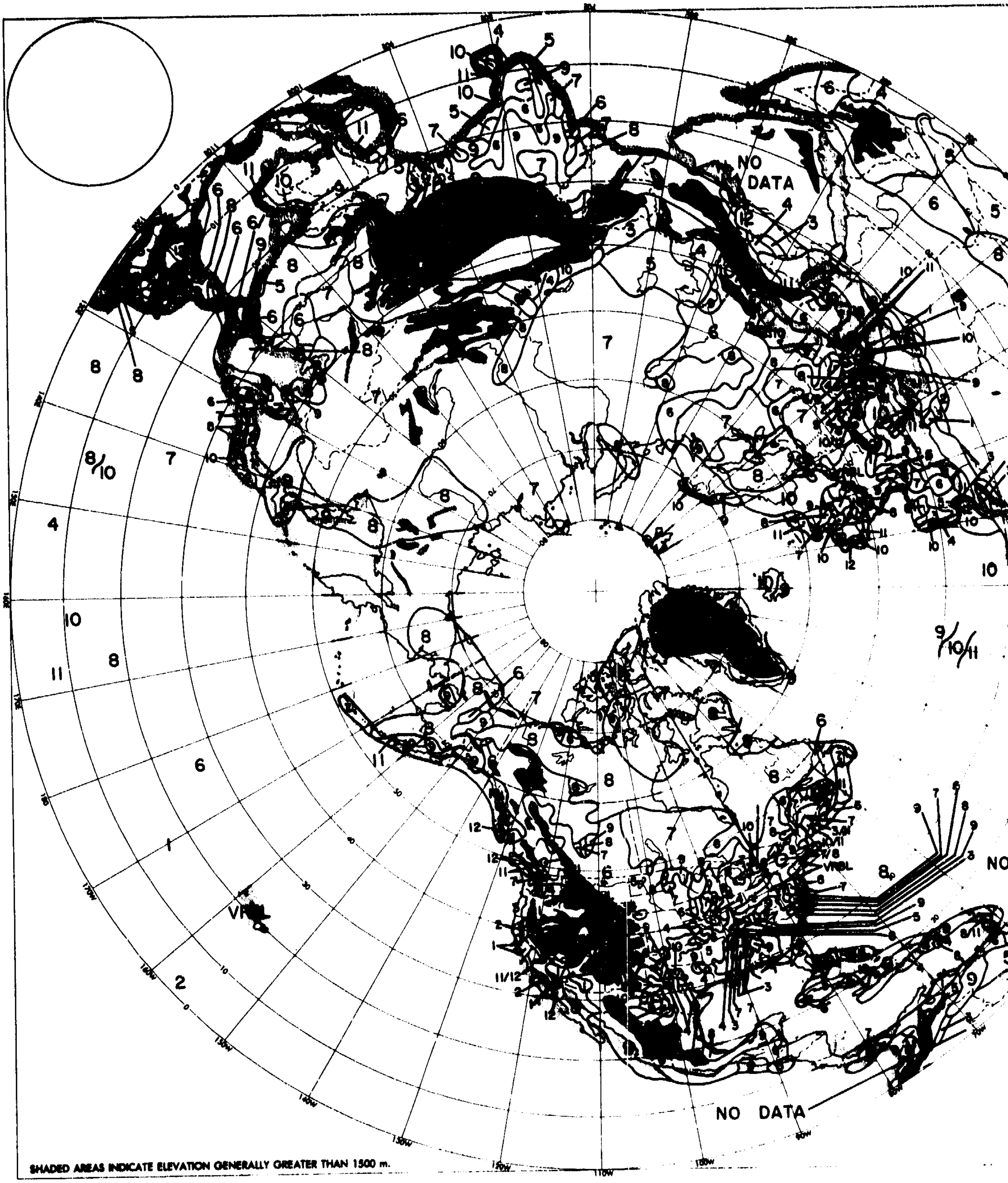
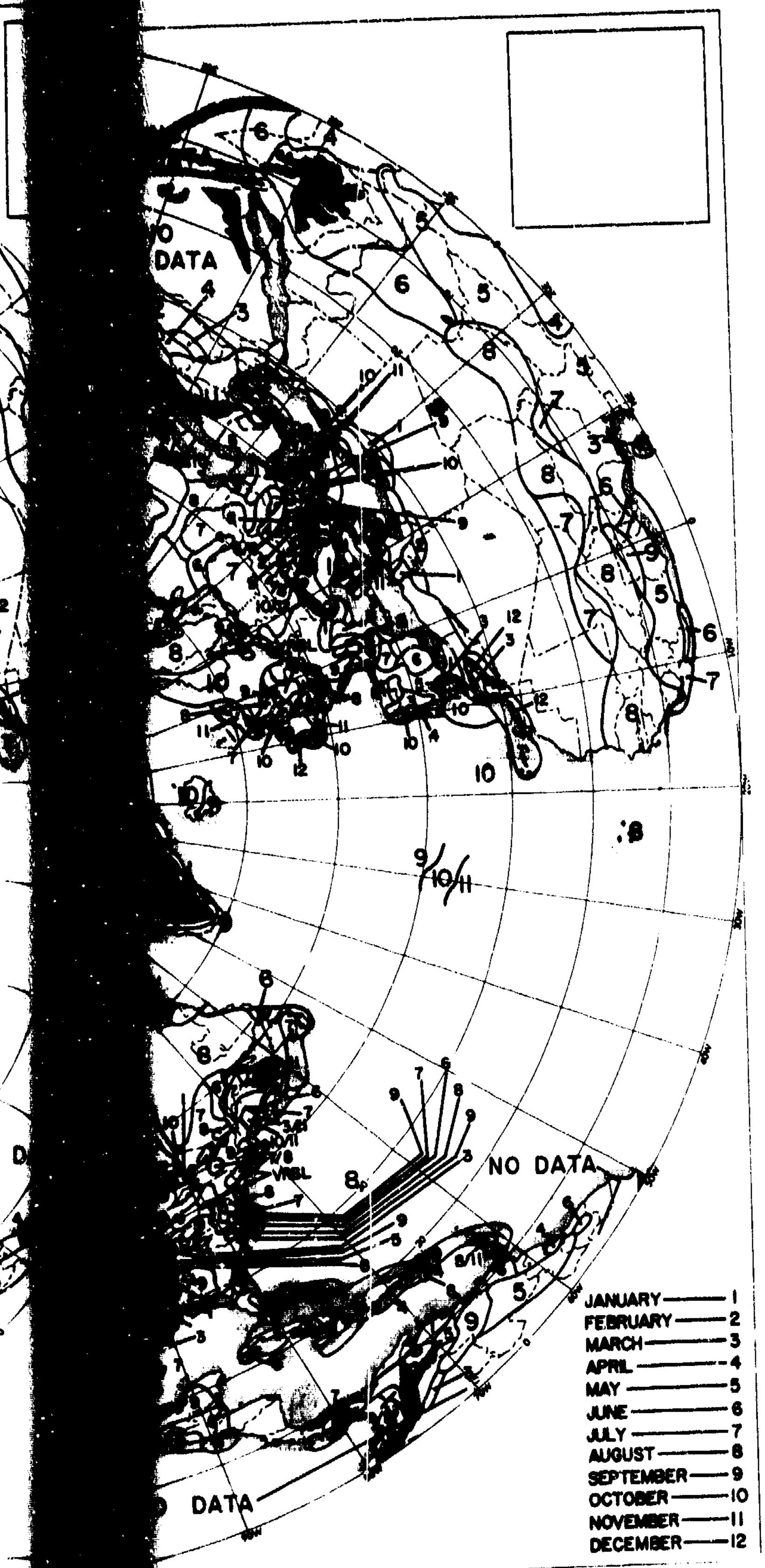


Figure 29. Month With the Highest 1-Min Rainfall Rates Equalled or Exceeded 0.50 Percent of the Time

2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JANUARY — 1
FEBRUARY — 2
MARCH — 3
APRIL — 4
MAY — 5
JUNE — 6
JULY — 7
AUGUST — 8
SEPTEMBER — 9
OCTOBER — 10
NOVEMBER — 11
DECEMBER — 12

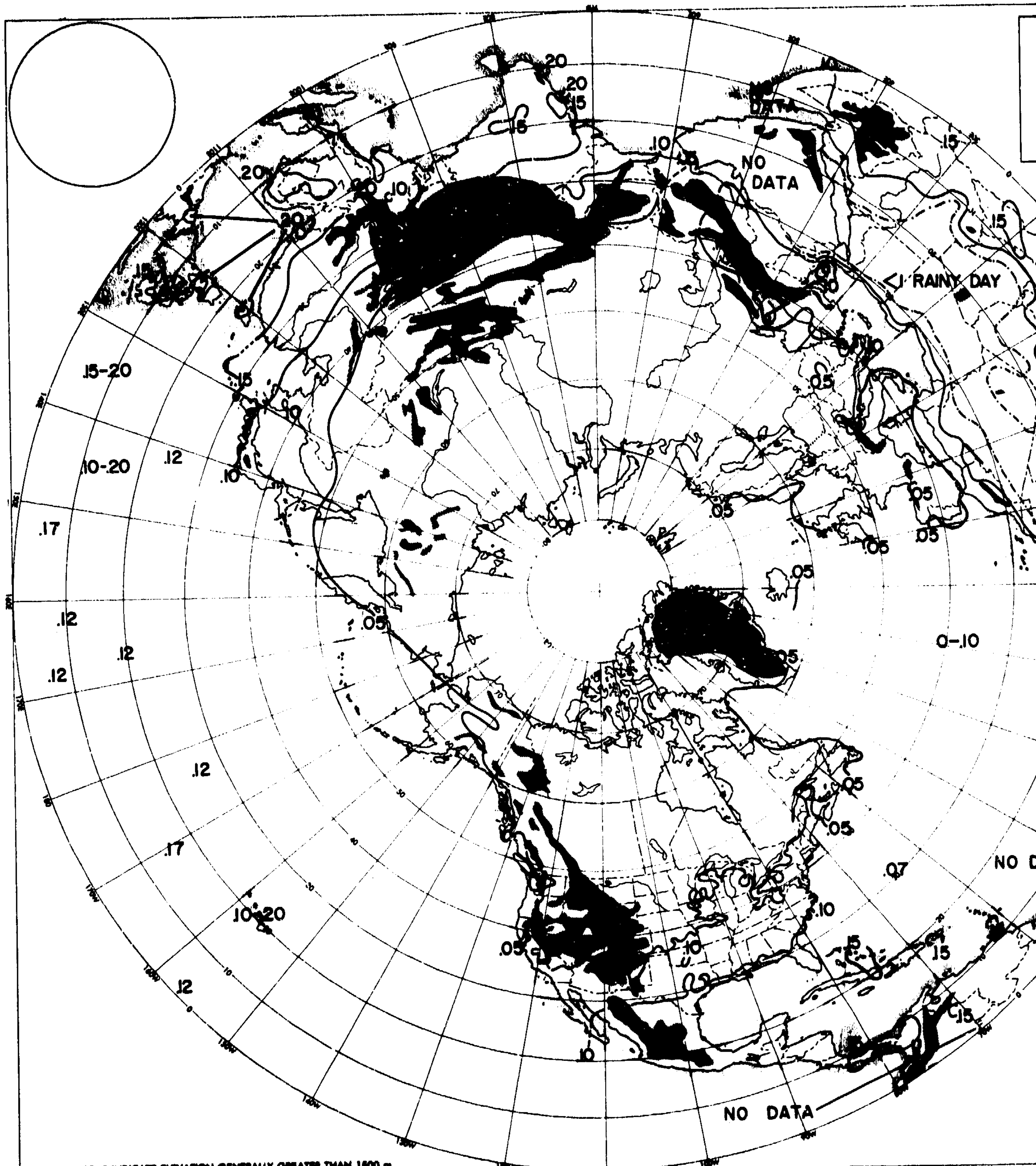
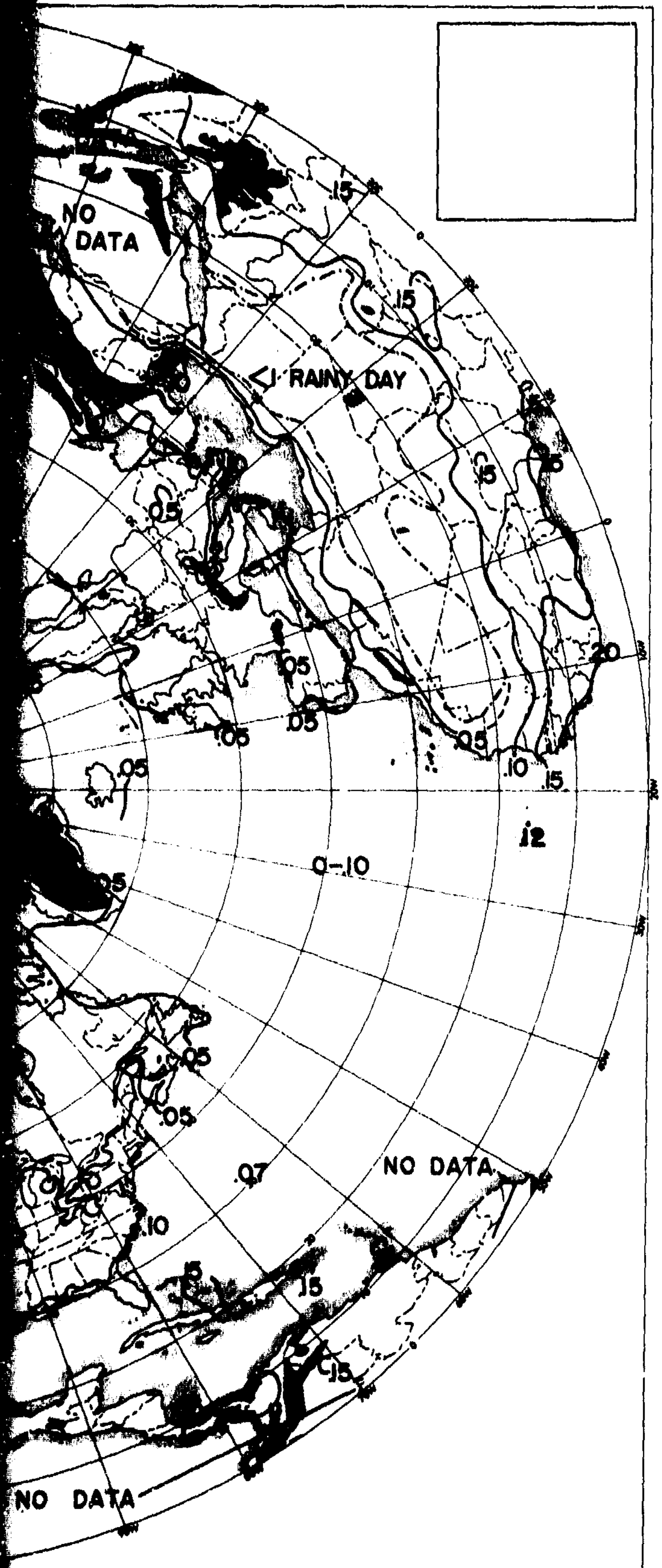


Figure 30. Highest 1-Min Rainfall Rates (mm/min) Equalled or Exceeded 1.0 Percent of the Time in Any Month

1 2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<1 RAINY DAY
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.15
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.10
.15
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.05
.05
.05
.07
NO DATA
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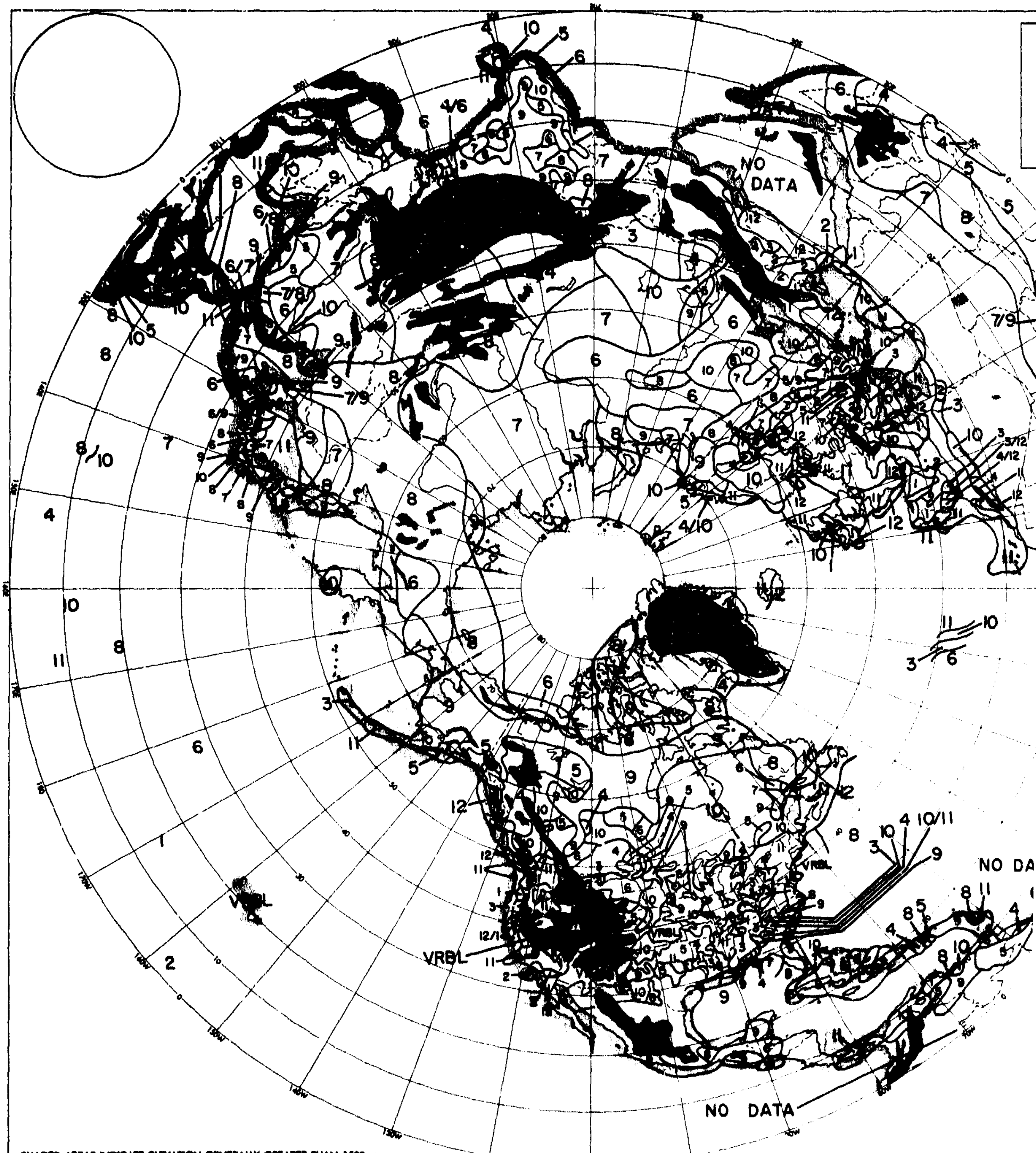
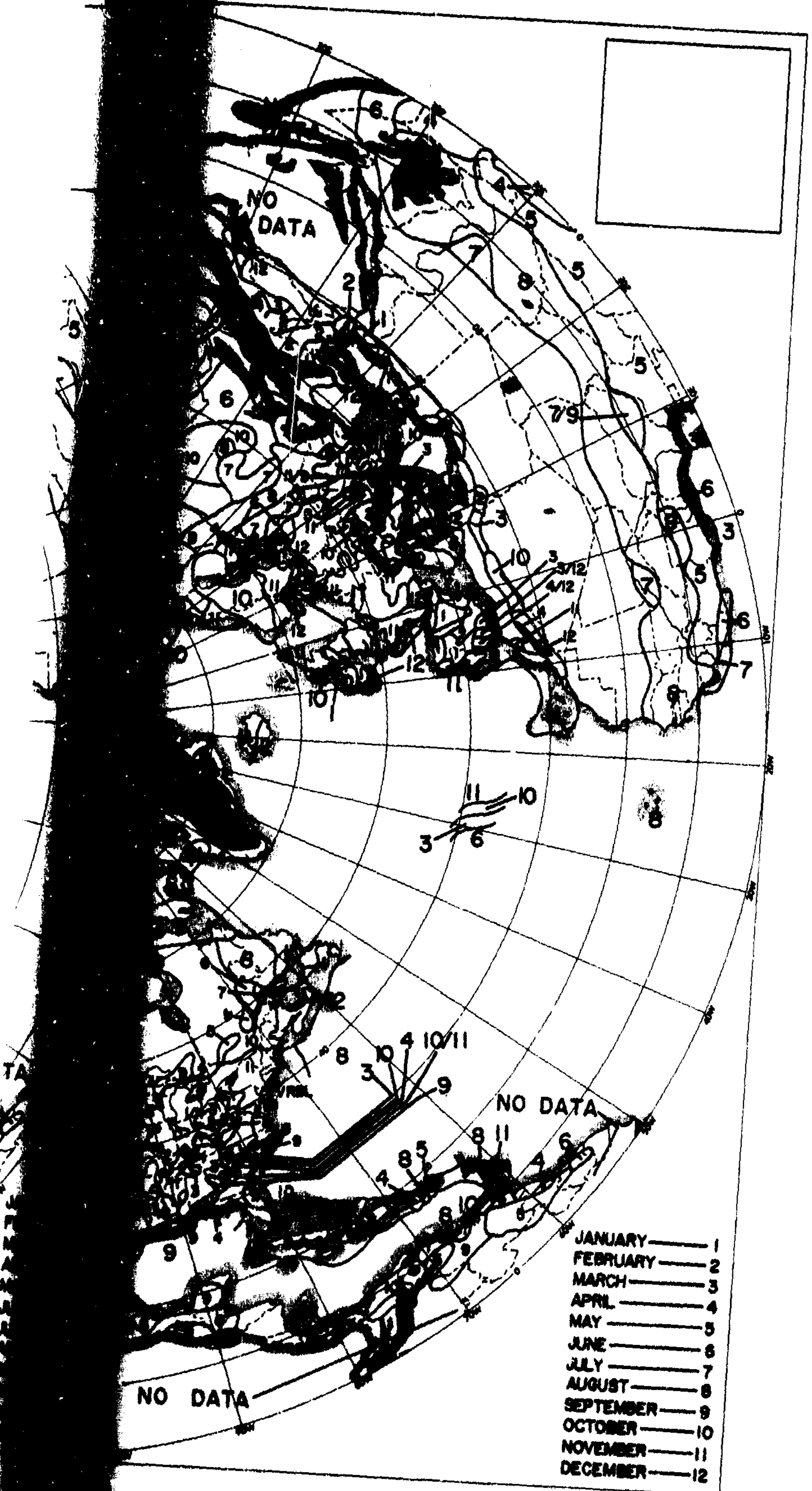


Figure 31. Month of the Year With the Highest 1-Min Rainfall Rates Equalled or Exceeded 1.0 Percent of the Time

2


NO DATA
NO DATA
NO DATA
JANUARY — 1
FEBRUARY — 2
MARCH — 3
APRIL — 4
MAY — 5
JUNE — 6
JULY — 7
AUGUST — 8
SEPTEMBER — 9
OCTOBER — 10
NOVEMBER — 11
DECEMBER — 12

or

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